Small remodel of Micro Ace 783 series

2004/2/15 Created
2004/3/4 Update

·introduction

The 783 series (Ariake specification) which I bought because I was born in Kyushu. The clean appearance is missing. Regarding proportions, well, it is a tough place, but there are too many complaints elsewhere.

1. The headlight is insanely dark. Prioritizing the taillight from the headlight, making an affair.
2. When incorporating the TOMIX interior light, the bridge diode part hangs over the guest room, and the streets are dark. If you incorporate it in the opposite direction, you can have the bridge diode part in the marginless window part. I am short of concern.
3. To use Katkap, it is a rotten power truck whose direction must be reversed. What happens with the direction of the yaw damper Gorua.

Regarding 1 and 3, there was already an example of countermeasures ("3 was awesome ... I ran it as it was") because " Tristar's toy box " at "Mr. Ariy 783 series small work ". I decided to try and manage the others by myself.

· Modification of head light / taillight

The light is " ~~fucking~~ dark" this vehicle. However, I did not understand how to remove the light unit, it was left for a while.
I was able to finish my hands at last until you learned how to remove the front head, such as the headlight unit for those who knows. This is pretty tricky and poor light guidance, how to receive light from the light bulb is also appropriate, it seems to be very inefficient. In addition, the headlight has more bend of the light guide rod than the tail light, and the light receiving part is also small.

"How to remove the forehead of type 783"
1. Remove the under floor from the car body.

2. Pulling the forehead while pushing the triangular window beside the cockpit room with a toothpick or the like, the forehead (and the light unit) disengages. Since the upper part of the forehead and the upper part of the car body are fitted with a thin boss, be careful not to break.

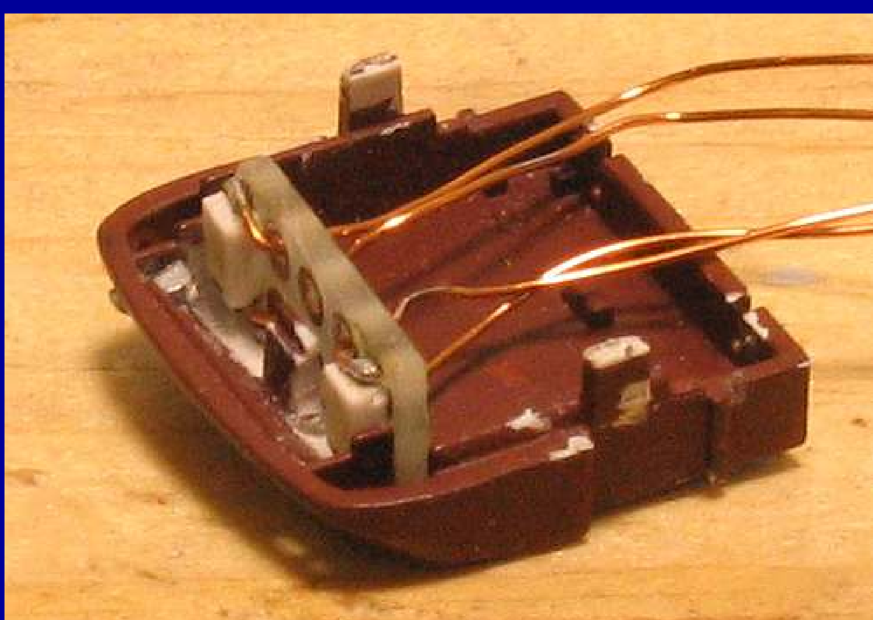
"Decomposition of light unit"
1. Extract the light unit from the forehead.
2. Because the light unit is divided into upper and lower parts, decompose the claws in a hurry.

I lighted the light-receiving part of the headlight light-guiding bar with "Mass-white LED indoor lamp Ver. 1.1" which was an idle asset on trial, but it is not bright at all. It seems that fundamental measures are necessary. Regrettably, the tail light glows pretty brightly when illuminating the light receiving part with the high brightness red LED on hand (- _ - #

" Tristar's toy box " says that we are reworking the light guiding part with optical fiber, but we wanted it to use the chip LED to illuminate the light part almost directly using the chip LED.

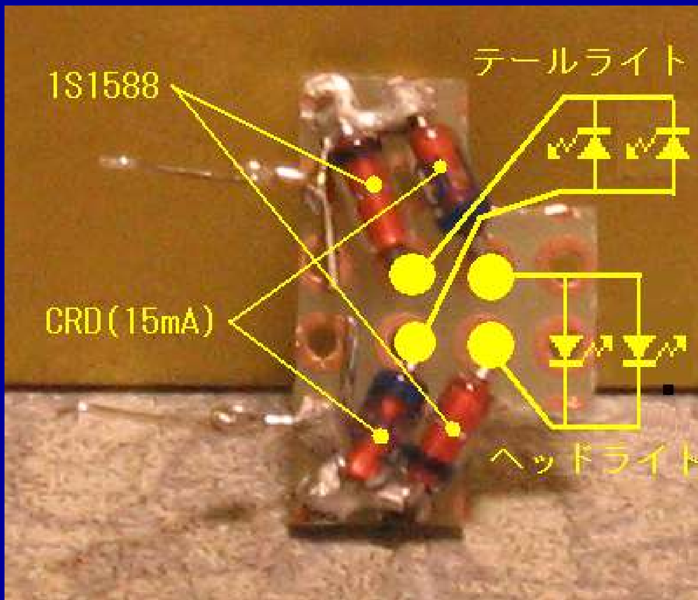
First of all, the light unit gently scrapes the partition board. There is a part to leave, so be careful.

Use the NSCW 100 sold in Akizuki Electronics for the chip white LED and solder it to the cut end of the universal board as shown below. Soldering chip LEDs can be done easily by positioning the LED on the board and using a clip or the like at "here" place.

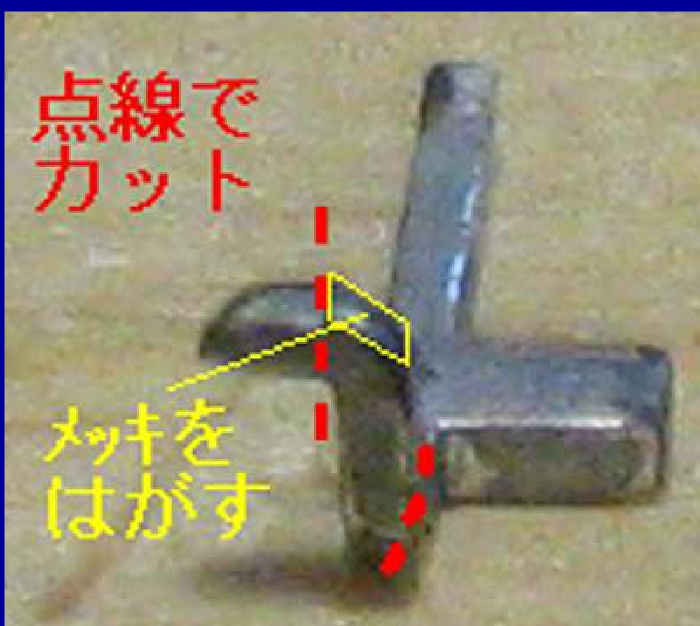


With this, the LED almost almost directly illuminates the light, and if it is 15 mA to this one, it is close to the homicidal ray
. As a result of various tests, as a result of 15 mA CRD, two white LEDs for headlight I decided to drive. Tail light as well. I do not know well how to use it, but I can use it without any problems.

Specifically, another small universal board was cut out and two pairs of CRD and diode (probably 1S 1588) were arranged here. A wrapping wire was used for the connection between the board carrying the LED and the substrate carrying the diode.



For the headlight lens and the taillight lens, the original light guide bar was cut and used in a linear shape. Although the taillight lens just cut the original light guide rod straightforwardly, in order to shorten the distance from the LED, the headlight lens used the crank shaped part of the original lens (see image below) as the light guide rod . The plating of the part to become a headlight lens is peeled off and polished.



For red LED I bought Agilent's HLMP-6300 small red LED at Suzuya. This was fixed with an epoxy adhesive properly (fine-tuned so that it could be seen evenly from the taillight holes). As a whole it was arranged like the image below.

(I tried PB-free solder, but it's hard to use ... I got dirty and soldered.)
After this, attach the light guide bar and attach it to the car body)

The direct light guidance effect is superb, and in this case it will not quit as well with the KATO 885 series white LED headlights. I used LEDs for the left and right headlights and taillights individually, so I was worried about the left and right difference, but there is no difference as far as I can see it (feeling that the difference will finally come to light at the limit of whether it shines or does not shine) is).

Tail light is also clearly like this.
Since the bottom side of the skirt is not connected to the original style, I cut it and attached TN coupler JC - 25

instead of a dummy coupler and attached it.

· Cut

the electric coupler in the lower stage by rounding and cutting the part of the spring on the rear side and the claws (By doing this, it can be fixed to the skirt with the front claws.

· Cut a part of the body train striking the skirt ·

Secure with glue so as not to swing the neck

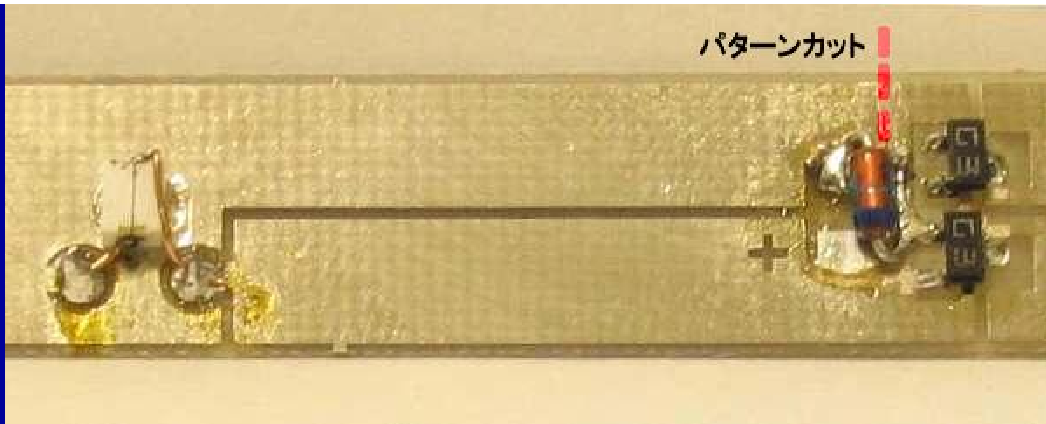
· Measures for indoor lighting

It was cheap (\ 150) Used TOMIX constant lighting Indoor light (0781, 0 0 0 0 0 0 2 0 2) was modified to easily make it a white LED. Although I thought that it is "Muramura it! Gorua" (**my own fault**), but when I see it well, the part where there is a bridge diode etc. of the interior lamp unit can not be said to be extremely dark Right end).

On the left side there are plenty of parts with no windows ... It is still improving, it is in the process of making.

after that:

Thinking about using two chip LEDs, I soldered two back-to-back NSCW 100 and fixed it with adhesive in the place where the light bulb was originally attached (on the left side of the image below). Because there is almost no fear of contact with wiring, we use ordinary copper wire. Also, I removed the original capacitor and attached a CRD there (right side of the image). The pattern cut is done at the position indicated by the red dotted line.



When it glows, it feels like this.

I got to shine evenly than before. There is something inevitable that the part of the diode is dark. I am planning to remodel it so that the installation of the interior lamp unit can be reversed left and right.

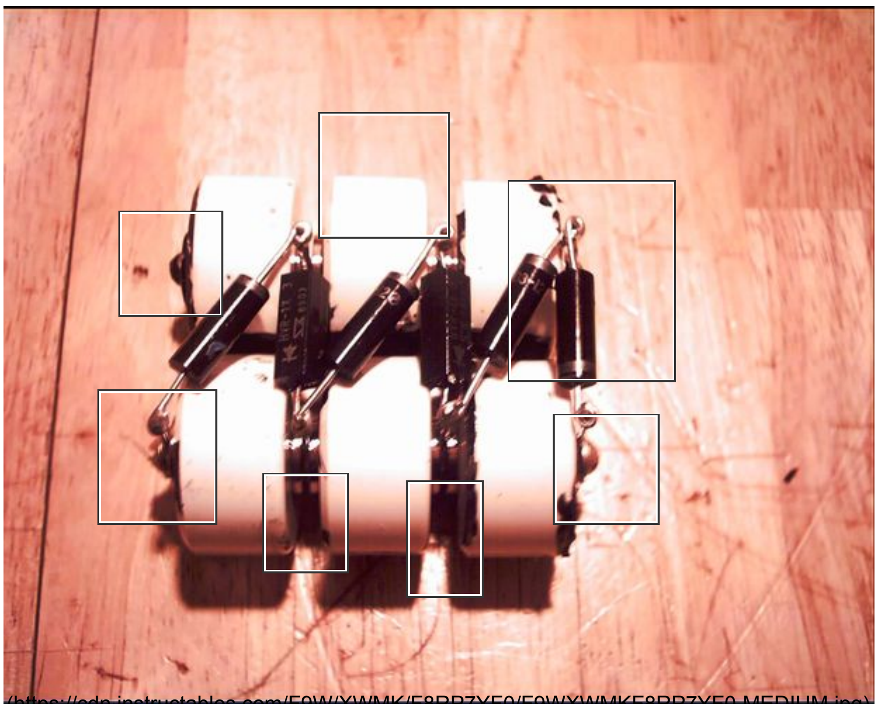
·bonus

With a little color insert, the image changes quite a lot.

The special devices on the roof are pretty noticeable in models with many opportunities to see from the top. The color used is copper, cockpit color, chrome silver (both are Tamiya enamel).

The first part is white with the car body cross section visible around the front glass which is blacked out ... It is not good ... I put black in the cross section of the body side of the front window and triangular window.

[HOME]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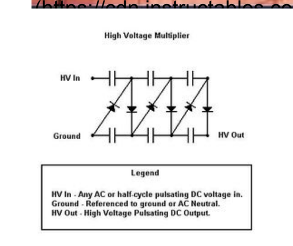

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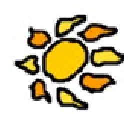
burningsuntech (/member/burningsuntec
(http://)
(/member/burningsuntech/)
Follow 83

Bio: I am a distant relative of the Apache Warrior Geronimo. I enjoy working with electronics, wood, metal and gold. I love the flashes of inspiration ... More » (/member/burningsuntech/)

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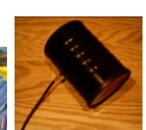
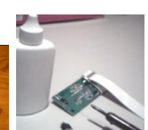

(/id/Maxwell-House-Wireless-Antenna/)


(/id/Make-your-own-Eco-friendly-soldering-flux/)

Need more voltage than your supply can deliver? This is the device to build.

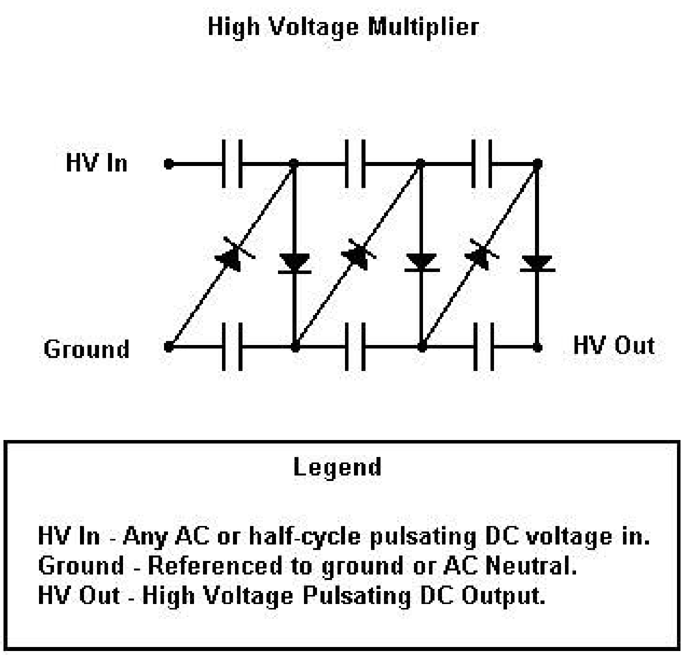
Based upon the Villard doubler, cascaded in multiple stages, this circuit will multiply a small AC voltage into a huge potential.

With a 6000 VAC Oil Burner Transformer and just three stages, you can multiply the potential from 6000 to 51,000 VDC!

Also, the higher the voltage ratings on your components, the higher the input voltage can be and therefore, more bang for your buck.

One side benefit of a stack like this is you can tap off various voltages from stage to stage. In this example, three outputs of 17000, 34000, and 51000 volts are available. Nice!

Step 1: The Theory



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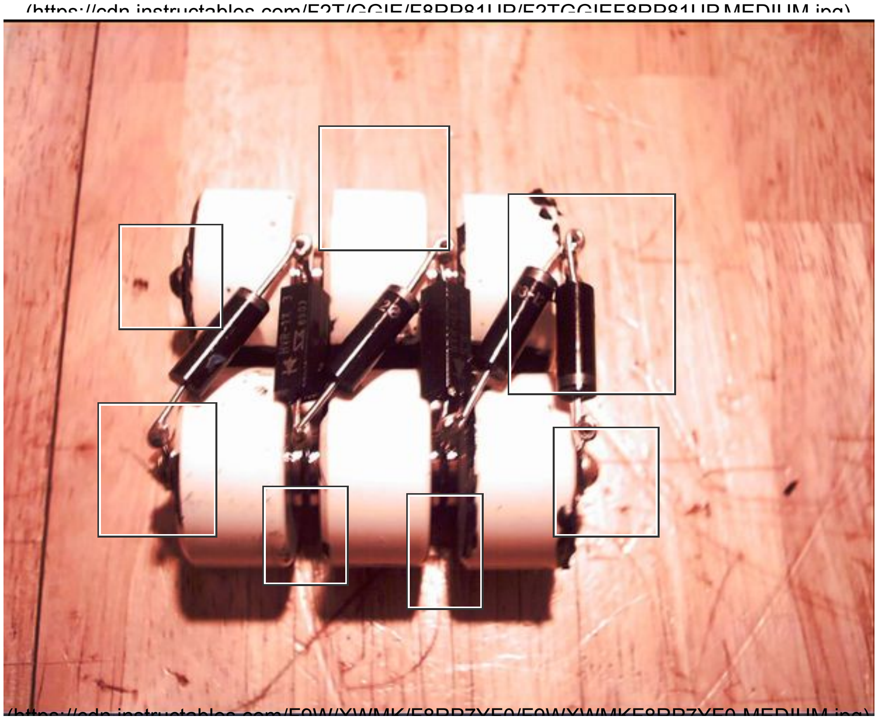

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Each stage of this multiplier is a doubler circuit and is made up of (2) Capacitors and (2) Diodes.

On the positive half-cycle of the input, the capacitors charge in parallel to the

peak value of the voltage presented through the forward biased diode. The other diode is reversed biased. Each cap charges to 8484 peak volts.

On the negative half-cycle of the input, the forward biased diode becomes reversed biased while the reversed biased diode becomes forward biased. This effectively connects the capacitors in series allowing them to discharge into the load at the output. The result is a doubled voltage presented to the load or 16968 peak volts.

Each connected stage adds its potential to the total output.

To calculate the expected voltage at the output with a given input and number of stages, plug the numbers into this formula:

Eout = (2 x Ein) x S x 1.414

Eout is the Output Voltage, Ein is the Input Voltage, and S is the number of stages in your design. I used a 6,000 VAC Oil Burner Transformer for my input and built 3 stages.

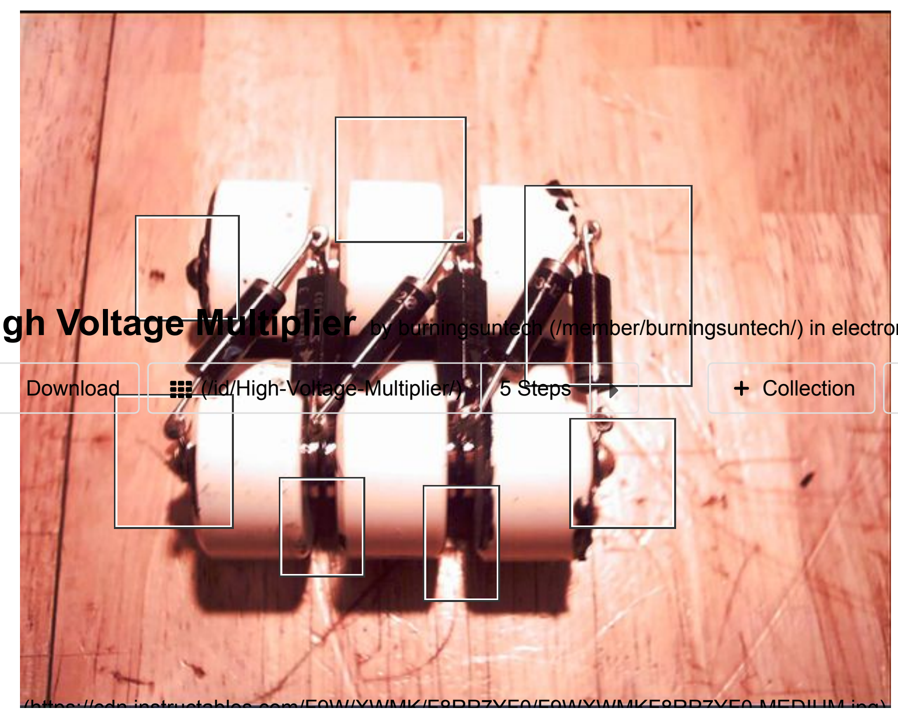
Eout = (2 x 6000) x 3 x 1.414

Eout = 12000 x 3 x 1.414

Eout = 36000 x 1.414

Eout = 50,904 volts

Step 2: The Parts List



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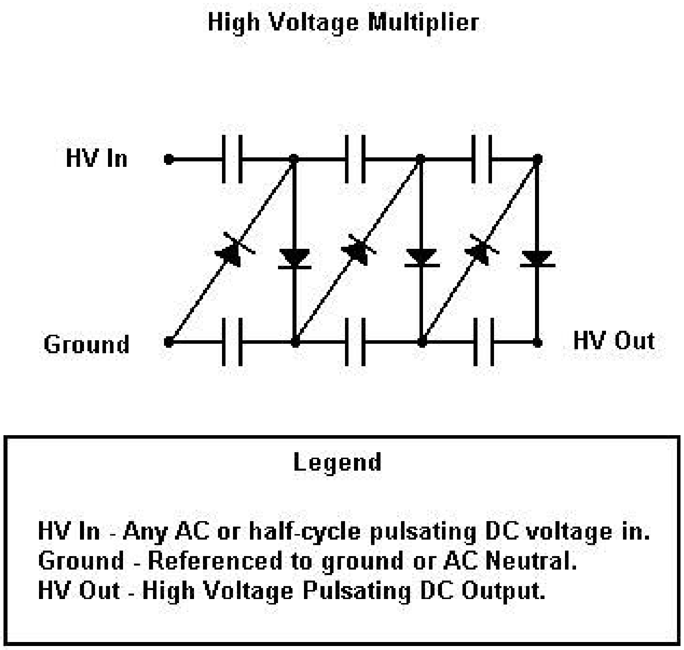

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All of the critical parts are available on EBay. Here's what you will need:

(6) 470 picofarad, 20KV Ceramic Doorknob Capacitors.

(6) HV03-12 12KV PIV High Voltage Diodes.

(7) Brass or copper wiring posts (homemade).

(8) 8-32 x 1 in. brass screws.

A length of 50KV High Voltage wire for the output.

A length of 20KV High Voltage wire for the input.

A length of 12ga. Stranded wire for ground.

(3) #8 Wire lugs.

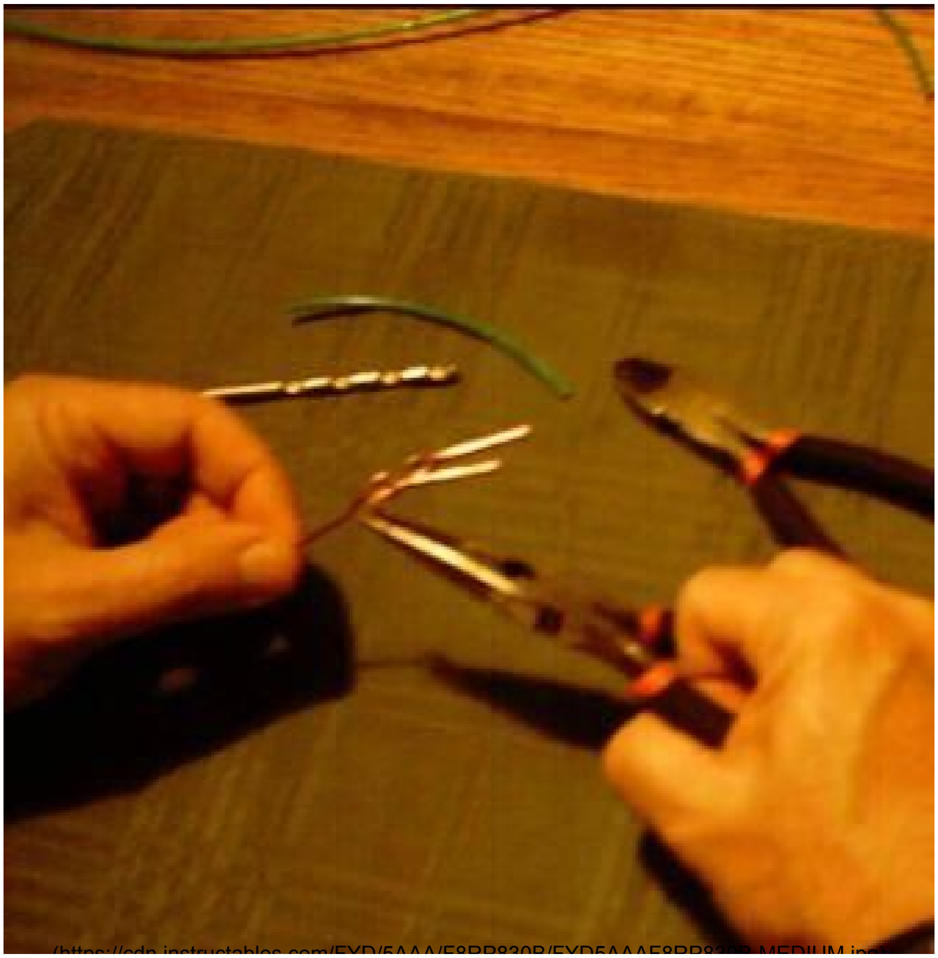
(1) Ziploc Food Storage Container big enough to hold the multiplier(not a bag).

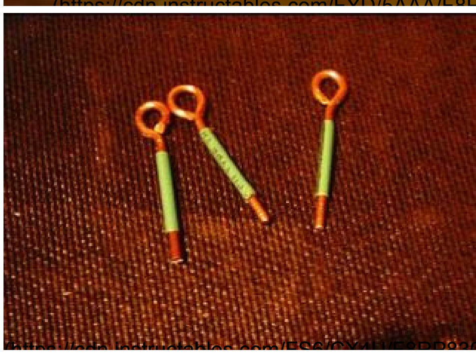
(1) qt. Mineral Oil.

RTV Silicon Rubber Sealant.

NOTE: Only the voltage rating on the components is critical.
The higher the rating, the higher the input voltage can be, resulting in a higher output voltage. The input limit on this design is 10KV (with safety margin built in). Ignition wire or coax cable with the shield removed may be substituted for high voltage wiring if need be.

Step 3: Build It!





This step isn't rocket science, just common sense building techniques. Just copy the design shown with the binding studs added.

Start by cutting (7) pieces of 16 guage brass or copper wire two inches long. Bend each piece around a drill bit and shape with a loop at one end.

Next, cut the heads off of four of the screws to make the studs that join the capacitors together.

Screw a stud into one of the caps. Place a binding post over the stud and screw on another capacitor. Screw in another stud, place a binding post over it and screw on the last capacitor.

Repeat the previous step to create two stacks of three caps each.

Lay the two stacks side by side with the binding posts pointing up.

Cut the four remaining screws to 1/2 inch long.

Attach binding posts to the right side end of each stack using a screw.

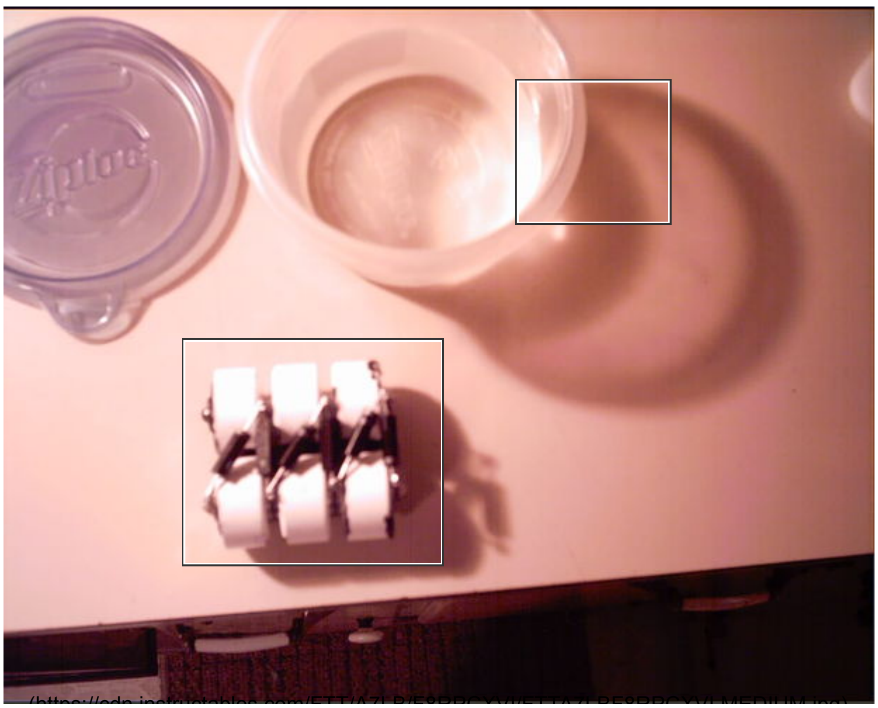
Attach a binding post to the left end of the bottom stack using a screw.

Attach the diodes as shown and solder them to the binding posts.

Cut off any excess binding post tops and file them flush to the soldered diodes. No sharp edge here or you will get an unwelcomed breakover which could ruin your project.

Attach the wires with lugs. Tighten the screws and make sure the entire assembly is tight.

Step 4: Bury It!



Now that the multilpier is finished, we need to encase it in oil.

With the lid still on the Ziploc container, punch three holes in the lid at the approximate locations where the leads will exit it. Remove the lid from the container and set it aside.

Slowly fill the empty, clean Ziploc container half way with mineral oil without creating any bubbles in the oil. Oil good! Air bad!

Hold the multiplier by its leads and slowly lower it into the oil bath.

Continue holding the leads with one hand and slowly pour more oil over the multiplier until it has at least a 1/2 inch covering and about 1/2 inch head space between the oil and the lid.

Now pass the leads one at a time through the holes in the lid then work the lid down onto the container while holding the leads. Do Not get oil on the leads at the lid level or the sealant won't stick or seal the wires. Snap the lid onto the container.

Finally, seal the leads and if you like, the lid to the container with the RTV sealant and set the project aside for 24 hours until the RTV is cured.

Your Done!

PLEASE READ THE SAFETY SECTION BEFORE POWERING THIS DEVICE! THANKS!

Step 5: Notes, Warnings, Safety Procedures and Disclaimer

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NOTES

This multiplier is part of a 0 to 50KV adjustable High Voltage Power Supply capable of sourcing 20 milliamps of current.

An instructable on building the supply is my next project, so hold on!

SAFETY WARNINGS and PROCEDURES

* * W A R N I N G * * *

This device produces LETHAL CURRENTS at HIGH VOLTAGE. The output of this device WILL KILL YOU if you do not follow standard common sense safety procedures.

Safety Precautions and Procedures

1. Wear safety goggles or glasses, rubber safety gloves, and stand on a rubber safety mat when powering or using this device.

2. GROUND the output of this device after powering it off. It can retain a lethal voltage for several minutes after powering down.

3. DO NOT TOUCH the device AT ANY TIME during operation.

4. Do not allow others who are not familiar with high voltage devices to touch or use this device without proper supervision.

5. Do Not operate this device alone! Have an emergency person available when performing your experiments who is familiar with proper rescue procedures.

DISCLAIMER

By building and operating this device, you acknowledge that you understand the

dangers improper operation can pose and you accept all risks associated with the operation of this device.

You also acknowledge that I am not nor will be responsible for any death or dismemberment by this device whatsoever and that you assume all risk by the use of this device.

Comments

be nice

We have a be nice comment policy.
Please be positive and constructive.

I Made it! | Add Images | Post Comment

MDA37 (/member/MDA37/) 2017-08-06 Reply

Hello sir,
Can we use DST flyback Transformer without capacitor which gives half cycle pulsating DC I think.
Would this circuit work?

MDA37 (/member/MDA37/) ▸ MDA37 (/member/MDA37/) 2017-08-06 Reply

Please answer me sir.
Anyone?

aclark17 (/member/aclark17/) made it! 2016-12-09 Reply

Here's my little guy, seems like this is the only reasonably priced type of cap you can get like this, unless anyone knows where to get the doorknobs for less than like $70 a piece?

Anyway, the first build was a lot tighter than this one and testing it burned out the OBT's primary and killed one of the diodes, so I got new diodes and remade

it with more room and tested it with a microwave oven transformer which, obviously not as much voltage, but enough to test and it works great! Now to replace my OBT....

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MDA37 (/member/MDA37/) ▸ aclark17 (/member/aclark17/) 2017-08-03 Reply

Hello sir,
Can I use "rectified" flyback transformer (new type), instead of AC flyback transformers (old type), for input power of this "capacitor and diode" combination circuit. Would this circuit work by input of "rectified flyback transformer".

aclark17 (/member/aclark17/) ▸ MDA37 (/member/MDA37/) 2017-08-05 Reply

I don't think it would work because flybacks are DC output aren't they? This whole voltage multiplication thing relies on the back and forth nature of AC

MDA37 (/member/MDA37/) ▸ aclark17 (/member/aclark17/) 2017-08-03 Reply

Hello sir,
Can I use "rectified" flyback transformer (new type), instead of AC flyback transformers (old type), for input power of this "capacitor and diode" combination circuit. Would this circuit work by input of "rectified flyback transformer".

tkalfaoglu (/member/tkalfaoglu/) ▸ aclark17 (/member/aclark17/) Reply 2017-04-11

Try ebay :) like 25 dollars for 8

MDA37 (/member/MDA37/) 2017-08-03 Reply

Hello sir,
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MDA37 (/member/MDA37/) 2017-08-03 Reply

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MDA37 (/member/MDA37/) 2017-08-03 Reply

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MDA37 (/member/MDA37/) 2017-08-02 Reply

hello sir,
Can I use "rectified" flyback Transformer instead of "AC" flyback transformer, to power up this "capacitor and diode" combination circuit. would this circuit work of input of rectified flyback transformer

HikmatB (/member/HikmatB/) 2016-02-27 Reply

if i want to make voltage multiplier 20kv with input 220V 50hz, what the best components to mak it?

hydranix (/member/hydranix/) ▸ HikmatB (/member/HikmatB/) 2016-02-27 Reply

You won't be able to make a 100x voltage multiplier like this. The high voltage diodes consume a considerable amount of the voltage. Further the cost of just the diodes would be more than $/€ 2000.

If you want 20kV from 220V mains, just use a transformer. Its FAR cheaper, and many times more efficient. Plus playing with 20kV, you need some serious insulation layers between the capacitors and diodes to prevent unwanted arcing.

2 12kV neon sign transformers would run you around $/€ 100-150.

Then rectifying that would be about another $/€ 100-150.

So using a multiplier would be more failure prone, much more dangerous, and cost easily 20 times a dual transformer setup.

If you want to really don't want to go the transformer route, don't use this circuit. Use a Marx generator. It doesn't suffer from the same diminishing returns as a multiplier. Though it has other drawbacks as well.

Be careful though. 20mA at 20kV will likely instantly kill you, and a Marx generator can easily exceed 100 to 200 times that current. One touch, anywhere on your body, and you're very dead.

HikmatB (/member/HikmatB/) ▸ hydranix (/member/hydranix/) 2016-03-01 Reply

do you ever made voltage multiplier, do you have id line? my id : hikmatsb

or my email hikmatsaefulbahri@gmail.com please answer

HikmatB (/member/HikmatB/) ▸ hydranix (/member/hydranix/) 2016-03-01 Reply

do you ever made voltage multiplier, do you have id line? my id : hikmatsb

or my email hikmatsaefulbahri@gmail.com please answer

HikmatB (/member/HikmatB/) ▸ hydranix (/member/hydranix/) 2016-03-01 Reply

thanks a lot for your information

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hydranix (/member/hydranix/) 2016-02-27 Reply

...and you don't experience any arcs between those unprotected solder joints?

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razara71 (/member/razara71/) 2016-01-17 Reply

Very nice article.

ToshikazuK (/member/ToshikazuK/) 2015-10-15 Reply

Will the multiplier work if I directly connect it the AC mains power supply?

AabcC (/member/AabcC/) 2015-09-01 Reply

hi, can I use different output capacitors in same multiplier? how to built a multiplier with different output capacitors?

---

crashstudio (/member/crashstudio/) made it! 2015-03-23 Reply

Encased in 3" PVC and filled with Paraffin wax. Caps are 20kv 470pf and diodes are 15kv 100ma. That's why I used 3 per connection. As far as the "ground" terminal I am assuming when using a 2 pole transformer (type 619 10kv OBT) I just connect 1 lead to HV in and the other to ground?

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crashstudio (/member/crashstudio/) 2015-03-20 Reply

I just finished building one to your spec and was wondering how to connect my 10kv OBT to it. There are 2 secondary terminals.

aclark17 (/member/aclark17/) 2013-04-28 Reply

Alright Ive thought on this for some time and I absolutely HAVE to ask... partly because some Im confused about and partly because no one else has.

First, my OBT is similar to the one used in this instructable, RMS 6kV. Peak to peak its 20kV, half wave obviously 10kV. Now burningsuntech, you said the RMS value is .707 of the peak value, and/or the peak value is 30% higher than the RMS, but my numbers dont equate, according to what the label on the OBT says my RMS should be 7070v, and yet it says its RMS is 6kV. So whats up with that?

The other part of my question is in the formula you give, Output voltage, Input voltage, and the number of stages are all represented as well as the action of each stage (that being Ein x 2), i.e. Eout = (2 x Ein) x (# of stages), but where are you getting the extra 41.4% output at the end there, represented by x 1.414? Its not mentioned, its just there?

I also wanted to say that even though Im confused on those minor details (not minor to me cause I wanna know :P) I have constructed the multiplier, connected the variac, which is an external one that I can keep outside the case and plug the supply into or use for other things as well, and connected the OBT to the multiplier using 20kV If its labelled TV-20/40/50 thats the kV rating) HV wire I got from flybacks, as well as a short length of 50kV (TV-50) for the output, and while I still have to fill the project box for the multiplier with wax (it DOES arc!!!! Blew a diode that way... just one though!) it works PERFECTLY! Its a very elegant project, and I am very proud of it. Thank you for your instructable and lessons on the theory of operation, its great!!!

aclark17 (/member/aclark17/) ▸ aclark17 (/member/aclark17/) 2013-04-28 Reply

Oh I forgot, I meant to ask if the x 1.414 was because of ripple or is it something else entirely?

aclark17 (/member/aclark17/) ▸ aclark17 (/member/aclark17/) 2013-12-20 Reply

Nevermind, I got it, the caps charging to the peak forward 8484v, which is 1.414 times the input of 6000v

aclark17 (/member/aclark17/) ▸ aclark17 (/member/aclark17/) 2014-06-29 Reply

It would have been really easy for me if someone would have just said the 1.414 is the square root of 2, part of the Root Mean Square lol

aclark17 (/member/aclark17/) 2013-12-18 Reply

Can you guys that are also making this multiplier tell me what diodes you use and why? I had some that worked, but I only had a couple extras and had some arcing that fried one a couple times so I have to get more and revise my construction and I'd like to hear what you other guys are using for this if not HV03-12 (hard to find and expensive, as far as I can see)

ymasamune (/member/ymasamune/) 2011-08-11 Reply

Hi, if for example i want to use this multiplier to multiple the output voltage from high frequency (say, in the kHz range) alternating current (say from ignition coil), would it be reliable to use diodes 1N4007? Or in simpler words, is 1N4007 suitable for hi freq AC?

mrp1232 (/member/mrp1232/) ▸ ymasamune (/member/ymasamune/) Reply 2012-04-28

Hey Ymasamune
I think your answer is no because the 1n4007 does not have a fast enough switching speed. At high enough frequency like in the kHz range the diode would conduct backwards. Here a youtube link i saw this at. It starts at 3:02
http://www.youtube.com/watch?v=cyhzpFqXwdA&feature=endscreen&NR=1

aclark17 (/member/aclark17/) ▸ mrp1232 (/member/mrp1232/) 2013-04-28 Reply

Couldn't he just get fast switching diodes though? I think the ones Im using aren't 1n4007, they're rated for enough voltage but the amperage is only 350mA, looking at the datasheet the switching speed is in the nanoseconds

mthomp1 (/member/mthomp1/) ▸ aclark17 (/member/aclark17/) 2013-10-16 Reply

The 1N4007 is rated at 1000 volts P.I.V., 1 amp. UF4007 is rated the same except the recovery is much faster than 1N4007. UF4007 recovery speed is 75 nS, the 1N4007 is 35 uS. The UF4007 is best on high speed switching circuits. See datasheets for UF4001 to UF4007.

aclark17 (/member/aclark17/) ▸ mthomp1 (/member/mthomp1/) 2013-12-18 Reply

Ah yeah I see

leviterande (/member/leviterande/) 2013-07-30 Reply

Hi, nice tutorial, I have a DST half wave modern type Flyback from CRt like this: http://www.electronicrepairguide.com/images/flyback1.jpg

Will it work for this multiplier? I have always wondered this but I coudnt find any answer

Thanks .

MulBe039 (/member/MulBe039/) 2011-12-10 Reply

will this also work with capacitors which aren't made out of ceramic?? i can't find 470pF ceramic ones, vut i found iothers for 470pF

aclark17 (/member/aclark17/) ▸ MulBe039 (/member/MulBe039/) Reply 2013-04-28

The capacitance doesn't have to be spot on, I saw a lot of caps that were like 580pF 20kV that would work just fine, it doesnt have to be exact but dont stray too much from what the design calls for. Ill try to find you a link where I saw them, but it seems much easier to get the correct style doorknob caps at a slightly higher capacitance @ 20kV, I ended up finding some russian 20kV 470 pF caps on eBay, the guy sells them often so look there. Theyre more cylindrical than what suntech uses, and you'll have to get creative with the assembly because they don't fit together real nice like his do, not to mention the metric thread size, but its doable, and theyre a hell of a lot cheaper than the actual "doorknob" style used in the pics.

---

aclark17 (/member/aclark17/) ▸ aclark17 (/member/aclark17/) 2013-04-28 Reply

Here is a link to a lot of four that I purchased from the seller I purchased them from. They came all the way from Ukraine, but the specs are exactly right and I didnt have a lot of trouble with assembly, I used thick solid copper wire like burningsuntech does, and threaded the end that isnt threaded with the metric size needed, and got the right nuts to fit so I could loop the wire from cap to cap, and had copper posts on the ends, and just wrapped/soldered the diodes to the copper. You may find a way to do it that is better for you, and to be honest, it wasn't worth the trouble of threading and finding the correct size die and nuts for it, so stay away from that, but here you go:

http://www.ebay.com/itm/4x-470pF-20kV-High-Voltage-Doorknob-Capacitors-K15-4-/200889917153?pt=Vintage_Electronics_R2&hash=item2ec5f8dee1

And check out places like these: http://vintageaudioandvideo.com/high-voltage-ceramic.html

Just run a google search, eventually you'll find some you can use. DO NOT buy them if they say 20kVAR!! Thats not the same thing! 20kV or as high as you want, and Id say anywhere from 330pF to 880pF should do alright, but theres far too many 470pF and 500/550/570pF to have to stray that far. Good luck with the hunt! They are rare and can be expensive!

Dreistein (/member/Dreistein/) 2012-05-01 Reply

hey i'd like to make a device i can attach to say my foot ,that if i touch someone they would get a shock basically like when you walk with socks over a carpet but the effect is automated. A guy made an ible https://www.instructables.com/id/The-mini-electrostatic-generator/ where he makes what im describing but its not very detailed. any ideas?

---

aswethinkyouare (/member/aswethinkyouare/) 2012-01-16 Reply

have you had anyone use this voltage multiplier and or your variable voltage supply in corona poling?

---

aclark17 (/member/aclark17/) 2011-11-09 Reply

Im wondering if someone here can help me out....

I have a transformer, an OBT, with an RMS of 6000v, and youd think, hey! This is exactly what the design calls for! But Lo and behold, Im looking at it in my hands, and it says on the label: "PRI: 120V, 60Hz, 35VA SEC: 20Kvpk, 35mA,

Midpt Grnd"

If the RMS is 6kV, how can the peak be 20kV? And can I still use this with 12kV rated diodes? Or should I get different ones rated for like, 25kV?

For the record, the OBT is a Beckett 51771U, A-type oil burner transformer, and everywhere Ive checked, its 6kV RMS

aclark17 (/member/aclark17/) ▸ aclark17 (/member/aclark17/) 2011-11-10 Reply

I think I figured it out:

I emailed the company, and they told me that they use half the sine wave for the ratings, but I found out that isn't completely true.

20kV peak is actually a peak-to-peak value of the transformer using the full sine wave, negative peak to positive peak. The RMS value is found using only peak value, which uses only half the sine wave. So that leaves me with 10kV peak. If you go by burningsuntech's math (which I am inclined to believe), the peak value will be 30% higher than the RMS value, or the RMS is 60% of the peak value. 60% of 10kV happens to be 6kV. Problem solved!

aclark17 (/member/aclark17/) ▸ aclark17 (/member/aclark17/) 2011-11-13 Reply

OK I see I have some math errors, they're not really, but how they are measuring the sine wave values and etc is more than I wish to go through to correct myself, but either way, if anyone has this same question/issue, its OK to use your transformer so long as the RMS is 6k!

ARJOON (/member/ARJOON/) 2011-07-20 Reply

i have 1 question. i only have 100pF capacitors with rating ranging from 2kV-5kV. i intend to use it to make an output of about 20kV. i'll be using an output of about 200-600V. how many stages can i make out of the it. because rating of the capacitor seems to be quite low

Fragmaster (/member/Fragmaster/) ▸ ARJOON (/member/ARJOON/) Reply 2011-08-11

Hi Arjoon,
I'm not an electrical engineer or anything, but I've had a bit of experience with high voltage as of late.

I think that you meant to say that you will be using an INPUT of about 200-600V, and if so, your 2kV-5kV capacitors should work. I assume that your INPUT power is in AC, because if its not, you're out of luck.

I believe that your capacitors will work because their voltage rating only needs to exceed the peak voltage of your INPUT (200-600V r.m.s. = 282-848V peak).

Unfortunately, for your very small input voltage, you will need A LOT of stages to get all the way to 20kV. If your input is 200V, you'll need about **35 stages!** If your input is 600V, you will need 11 or 12 stages.

ankitgarg2005 (/member/ankitgarg2005/) 2011-07-24 Reply

how can I double a 6V 4.5Ah battery into 12v battery with 2A current or more.

Mr. Apol (/member/Mr.+Apol/) 2011-03-22 Reply

Success! Well, sort of . . .

I finished my multiplier, and hooked it up to a 7,500 volt neon sign transformer. I used the output to power an ion "thruster," but the results were disappointing. Using the HV outout of an old CRT monitor, the thruster moves vigorously. Using the multiplier/NST combo, I got a little bit of thrust, hissing, and a stream of ions, but not enough to make the thrusters turn. Since the output of the CRT is around 25,000-27,000 volts, I suspect I am not getting as much from the multiplier. According to calculations, I should be getting 60,000 volts, but I don't think I am. Since I am using recycled diodes, maybe some of them are defective? I checked the doorknob caps and found them within spec. I did not check the diodes.

Paul

qazwsx755 (/member/qazwsx755/) 2010-08-26 Reply

will a 10kv 23ma transformer work?

burningsuntech (/member/burningsuntech/) ▸ qazwsx755 (/member/qazwsx755/) 2010-08-27 Reply

Good Question, Q. The voltages on all AC devices are usually shown as the R.M.S. (root mean square) of the actual Peak value of that voltage. Your 10,000 volts R.M.S. would be 14,100 volts peak-to-peak or just 12,293 volts peak. The average voltage (R.M.S.) is .707 of the peak voltage. We know that 10,000 volts is .707 of the peak or 70% of the peak voltage. That means that the peak is 30% more than the average or in this case about 13,000 volts. I need to know the peak figure so I can determine if the P.I.V (peak inverse voltage) of the diodes can withstand that high a voltage and in this case... They cannot!. The diodes have a PIV of 12,000 volts. If you put a peak voltage of 13,000 volts across these diodes, all you will get is lots of smoke and not much more. What I telling you is that the peak voltage of your transformer is higher that the PIV of the diodes by 1000 volts and you will destroy them. If you get diodes with a PIV of say 15,000 volts, then you will be safe using this transformer. The capacitors in this multiplier have a much higher rating and you dont need to worry about them until you reach 20,000 volts on the input. The diodes, however, have to be changed. RA

Mr. Apol (/member/Mr.+Apol/) ▸ burningsuntech (/member/burningsuntech/) Reply 2011-03-14

Pardon me for breaking in here . . . if I follow you, then I could use a 7,500 volt NST with a multiplier built with 20kV doorknob caps and microwave oven (HVR-1X3) diodes, which are rated at 12kV?

The (max) result would be output of 63,630 V DC?

thanks,

Paul

burningsuntech (/member/burningsuntech/) ▸ Mr. Apol (/member/Mr.+Apol/)

2011-03-15 Reply

Correct.
Give the man a kupie doll.
One change I would maKE in the build is to use parafin instead of oil in the multiplier case. Its easier to use and it is easier to seal the container. I left mine open with no problems and was able to get it to maximum voltage

You might consider using a higher amperage Variac as well. Mine was too close to tolerance with the transformer running at 2.25 amps and my variac was for 2.5 amps. A bit too tight.

Have fun.
RA

Mr. Apol (/member/Mr.+Apol/) ▸ burningsuntech (/member/burningsuntech/)

Reply 2011-03-17

Thanks for your reply. I put the multiplier together today. Haven't tried it yet, but I have just a couple of simple questions.

The input Ground goes to a real ground, like a pipe in the back yard?

The low voltage (relatively speaking) input is going to come from an NST--the NST has two output lines; which one do I use, and what do I do with the NST line I don't use? Just isolate it?

The output is + DC, correct?

Thanks,

Paul

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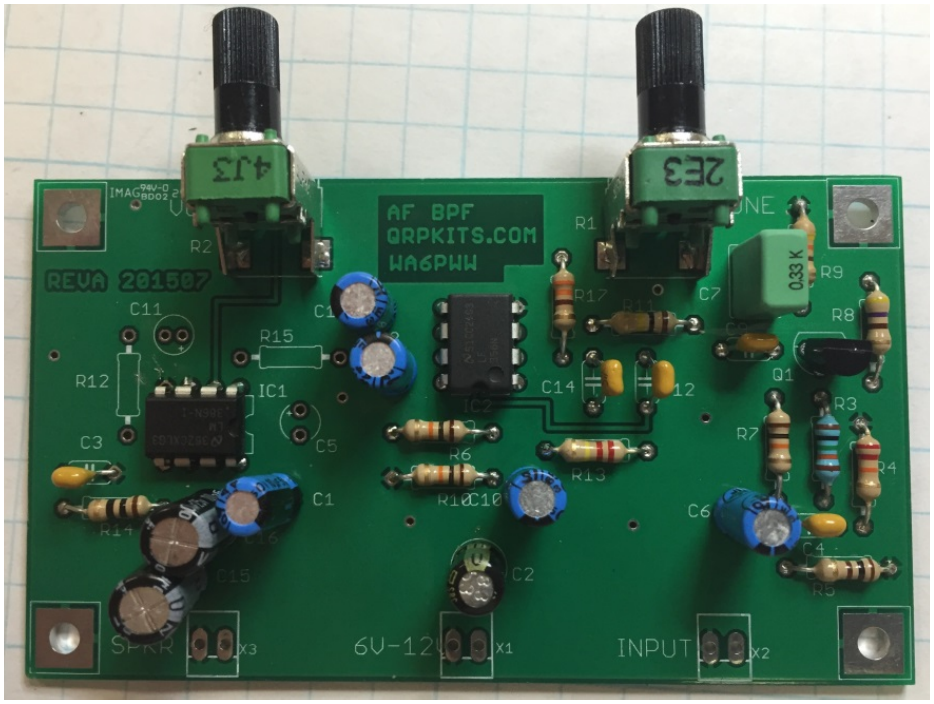
Pacific Antenna Easy Audio Bandpass Filter Kit



Description and Specifications

The Audio Frequency Band Pass Filter kit from qrpkits.com provides A basic audio filter kit .

Incorporates a transistor preamp, op-amp based filter and an LM386 audio amplifier to drive headphones or speaker.

Has a peak in audio response that is tunable from approximately 300Hz to 2Khz

Has a bandwidth of approximately 500Hz.

Designed to provide improved audio filtering and amplification to CW reception or other devices that may not have sufficiently narrow bandwidth.

The kit may be powered from 9-12Vdc.

Support

PACIFIC ANTENNA
QRP KITS.COM
qrpkits.com@gmail.com

Tools Needed

- ◻ Temperature Controlled Soldering Station with small tip
  or 15-35 watt soldering iron with small tip.
- ◻ Solder 60/40 or 63/37 Tin-Lead
- ◻ Small Diagonal Cutters
- ◻ Small Needle Nose Pliers
- ◻ Pencil, Pen, and/or Highlighter
- ◻ BRIGHT work light

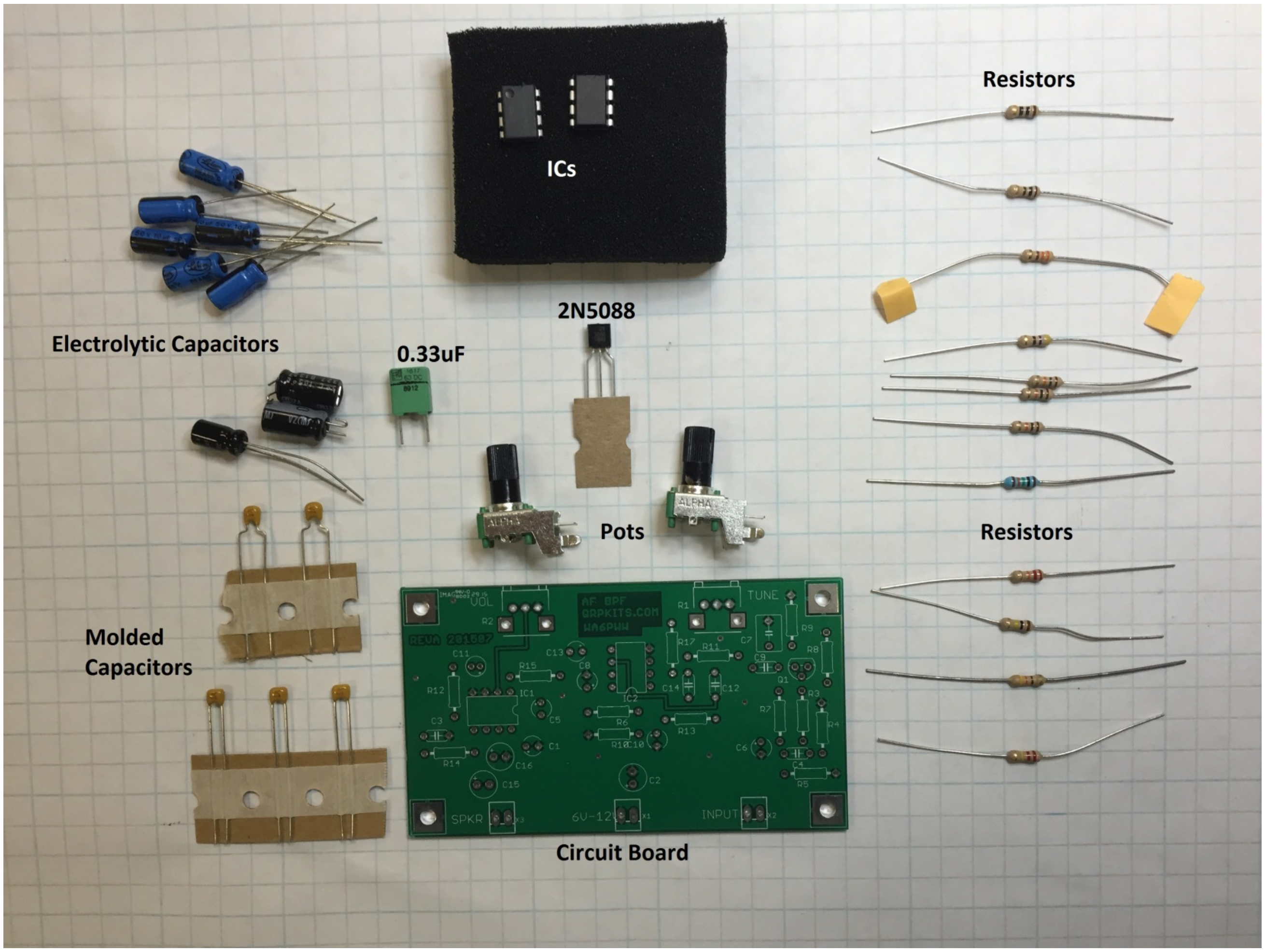
Optional

- ◻ Magnifying headpiece or lighted magnifying glass.
- ◻ Multi-meter
- ◻ Solder Sucker or Solder Wick
- ◻ Small multi-blade Screw Driver
- ◻ Knife or Wire Stripper
- ◻ Small Ruler
- ◻ Cookie Sheet to build in and keep parts from jumping onto the floor.

Construction Techniques

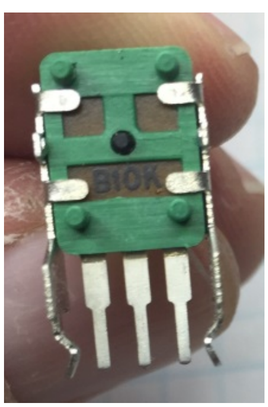
- ◻ There is no need to print out the whole assembly manual unless you want a copy. Print the Parts List and Schematic (last two pages) then view the rest of the manual on a computer, laptop, or tablet.
- ◻ The Parts List has columns for inventory and construction.
- ◻ Please take time to inventory the parts before starting. Report any shortages to QRPKITS.com (In many cases it may be faster and cheaper to pull a replacement from your parts supply, but please let us know if we missed something.)
- ◻ There is no need to print out the whole assembly manual unless you want a copy. Print the
- ◻ Pre-sorting the resistors and capacitors can speed up the assembly and reduce mistakes.
- ◻ You can insert several parts at a time onto the board. When you insert a part bend the leads over slightly to hold the part in place, then solder all at the same time. Clip the leads flush.
- ◻ Most parts should be mounted as close to the board as possible. Transistors should be mounted about 1/8” above the board. Solder one lead on ICs or IC sockets and then check to make sure the component is flush before soldering the remaining leads.
- ◻ Use a Temperature Controlled Soldering Station with small tip or 15-35 watt soldering iron with small tip. Conical or very small screw driver tips are best.
- ◻ DO NOT use a large soldering iron or soldering gun.
- ◻ If you are a beginner, new to soldering, there are a number of resources on the web to help you get on the right track soldering like a pro. Google Soldering Techniques. Here is one good example: http://www.elecraft.com/TechNotes/N0SS_SolderNotes/N0SS_SolderNotesV6.pdf

Parts Identification:

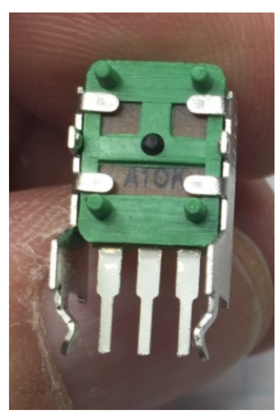


Note: This is a general guide. The parts supplied in the kit may vary slightly in appearance from those shown in this photo and not all parts included in the kit are shown.

Linear Potentiometer R1



Audio Potentiometer R2



Inventory and Parts List

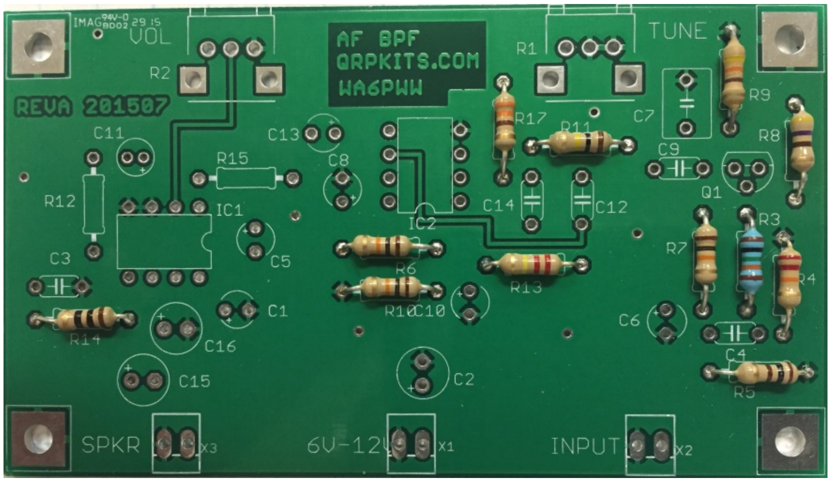
The first column is for inventory of parts and the second is to track as they are installed

Inventory	Installed	Part	Value	Identification	Description
		R14	10	Brn-blk-blk-gold	10 Ohm 1/4W resistor
		R5	100	Brn-blk-brn-gold	100 Ohm 1/4W resistor
		R17	330	Org-org-brn-gold	330 Ohm 1/4W resistor
		R9	430	Yel-org-brn-gold	430 Ohm 1/4W resistor
		R8	470	Yel-vio-brn-gold	470 Ohm 1/4W resistor
		R7	6.8K	Blu-gry-red-gold	6.8K Ohm 1/4W resistor
		R6	10K	Brn-blk-org-gold	10K Ohm 1/4W resistor
		R10	10K	Brn-blk-org-gold	10K Ohm 1/4W resistor
		R4	15K	Brn-grn-org-gold	15K Ohm 1`/4W resistor
		R3	100K	Brn-blk-yel-gold	100K Ohm 1/4W resistor
		R11	100K	Brn-blk-yel-gold	100K Ohm 1/4W resistor
		R13	220K	Red-red-yel-gold	22OK Ohm 1/4W resistor
*		R12	*Not Used		
*		R15	*Not Used		
		C9	0.01uF	103	Monolythic capacitor
		C12	0.01uF	103	Monolythic capacitor
		C14	0.01uF	103	Monolythic capacitor
		C3	0.1uF	104	Monolythic capacitor
		C4	0.1uF	104	Monolythic capacitor
		C7	0.33uF	0.33	Rectangular Film Capacitor
		C1	10uF	10uF electrolytic	Round can electrolytic capacitor
		C6	10uF	10uF electrolytic	Round can electrolytic capacitor
		C8	10uF	10uF electrolytic	Round can electrolytic capacitor
		C10	10uF	10uF electrolytic	Round can electrolytic capacitor
		C13	10uF	10uF electrolytic	Round can electrolytic capacitor
		C2	47uF	47uF electrolytic	Round can electrolytic capacitor
		C15	100uf	100uF electrolytic	Round can electrolytic capacitor
		C16	100uf	100uF electrolytic	Round can electrolytic capacitor
*		C5	*Not Used		
*		C11	*Not Used		
		Q1	2N5088	2N5088	Plastic, TO92 Transistor
		Socket	8 pin	8 Pin IC Socket	Black plastic socket for ICs
		Socket	8 pin	8 Pin IC Socket	Black plastic socket for ICs
		IC1	LM386	LM386	8 Pin IC
		IC2	LF356	LF356N	8 Pin IC
		R1	10K linear pot	B10K	9mm square rotary potentiometer
		R2	10K audio pot	A10K	9mm square rotary potentiometer
		Knob	Small Knob	black knob	Tuning knob
		Knob	Small Knob	black knob	Volume knob
		Connector	9V snap	9V battery connector	9V battery snap with leads
		Connector	3.5mm	Audio in	3.5mm audio jack
		Connector	3.5mm	Audio out	3.5mm audio jack
		Wire	3ft	Hookup wire	3 Colors 1 ft each
		PCB	Board	Circuit Board	AF BPF PCB Rev A1 or later

Inserting the Parts

Resistors

Sort the resistors by value insert them smallest value first, largest value last. There are 3 - 10K resistors and one of each of the others. Be sure to check the color code for each resistor as you install. [Measuring with an Ohm meter is a good idea.]



□	R14	10	brn-blk-blk-gold
□	R5	100	brn-blk-brn-gold
□	R17	330	org-org-brn-gold
□	R9	430	yel-org-brn-gold
□	R8	470	yel-vio-brn-gold
□	R6	10K	brn-blk-org-gold
□	R7	6.8K	blu-gry-red-gold
□	R10	10K	brn-blk-org-gold
□	R4	15K	brn-grn-org-gold
□	R11	100K	brn-blk-yel-gold
□	R3	100K	brn-blk-yel-gold
□	R13	220K	red-red-yel-gold

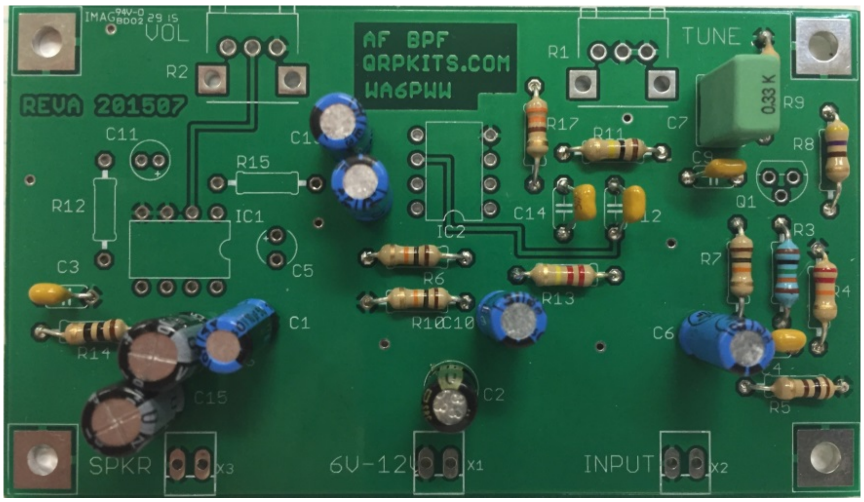
Capacitors

Next insert the molded capacitors. There are 3 - 0.01uF, 2 - 0.1uF, and 1 - 0.33uF. The 0.01uF and 0.1uF capacitors look very similar, double check the markings.

□	C9	0.01uF	103
□	C12	0.01uF	103
□	C14	0.01uF	103
□	C3	0.1uF	104
□	C4	0.1uF	104
□	C7	0.33uF	0.33K

Electrolytics

Now insert the electrolytic capacitors. These capacitors are polarized. The negative lead is marked with a black bar on the side of the capacitor.



□	C1	10uF	10uF
□	C6	10uF	10uF
□	C8	10uF	10uF
□	C10	10uF	10uF
□	C13	10uF	10uF
□	C2	47uF	47uF
□	C15	100uF	100uF
□	C16	100uF	100uF

Remaining Parts

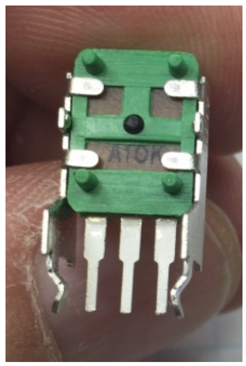
Now install Q1 the 2N5088 transistor. Follow the layout orientation on the board. The flat side of the transistor should match the flat side of the diagram.

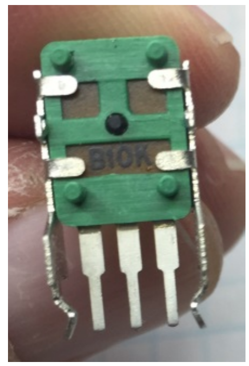
□ Q1 2N5088

Next install the two IC sockets and the ICs. Make sure the orientation notch on the IC matches the orientation notch on the circuit board.

□ IC1 LM386
□ IC2 LF356

The last 2 parts to install are the two potentiometers. The A10K and B10K identification marks are on the back of the pots and are a bit difficult to read. Use lots of light. Be sure that the B10K pot goes in the spot for R1 and the A10K goes in the location for R2 on the circuit board.





□ R1 10K Linear Pot (B) B10K
□ R2 10K Audio Pot (A) A10K

Hooking Up the Audio Frequency Band Pass Filter

The ABPF requires 8 - 12V DC. The power may be supplied from a companion kit, a small power supply, or a 9V battery using the battery clip that is included in the kit.
If using an AC operated supply, it should be well regulated and filtered to prevent hum or other noise being added to the audio. An inline fuse of 1A or less is recommended when an AC power supply or 12V battery is used.

Due to the many possible configurations, audio Input and output connections are also left up to the builder. The AFBPF may be wired directly into a receiver or speaker cabinet. Alternatively, the included jacks installed and 3.5mm plugs may be used for input and output connections. The kit is capable of directly driving a small speaker.

When the kit is first powered after assembly, it is recommended to use a battery or conenct an inline fuse or a power supply with the current limited to approximately 100-200mA to prevent damage if there are shorts. If you notice large power draw, stop and go back and inspect the board for any shorts or components installed incorrectly.

When the kit is first powered, you should hear static in the speaker or headphones that varies as the volume control is turned. If not, recheck the board for shorts and component errors.

If you have passed this step, you can connect an input audio signal from a receiver or other source of CW signals and you should hear the signal through the output. Moving the tuning knob will place the peak response on the chosen signal.

Packaging

Packaging is left up to the builder. The AFBPF can be built into another kit, or radio cabinet, installed in a speaker cabinet, or installed into a case.

Operation

R1 on the left side of the board is the tuning adjustment, tune to the desired listening frequency by peaking the audible sound on the chosen signal.   This will have the affect of amplifying the desired signal while attenuating signals that differ in frequency.

R2 located on the right side of the board is the volume adjustment. Adjust for a comfortable listening level.

If the signals sound distorted, this is likely due to too much audio signal on the input. Reduce the input audio level from the source until the signals sound clean.

Troubleshooting

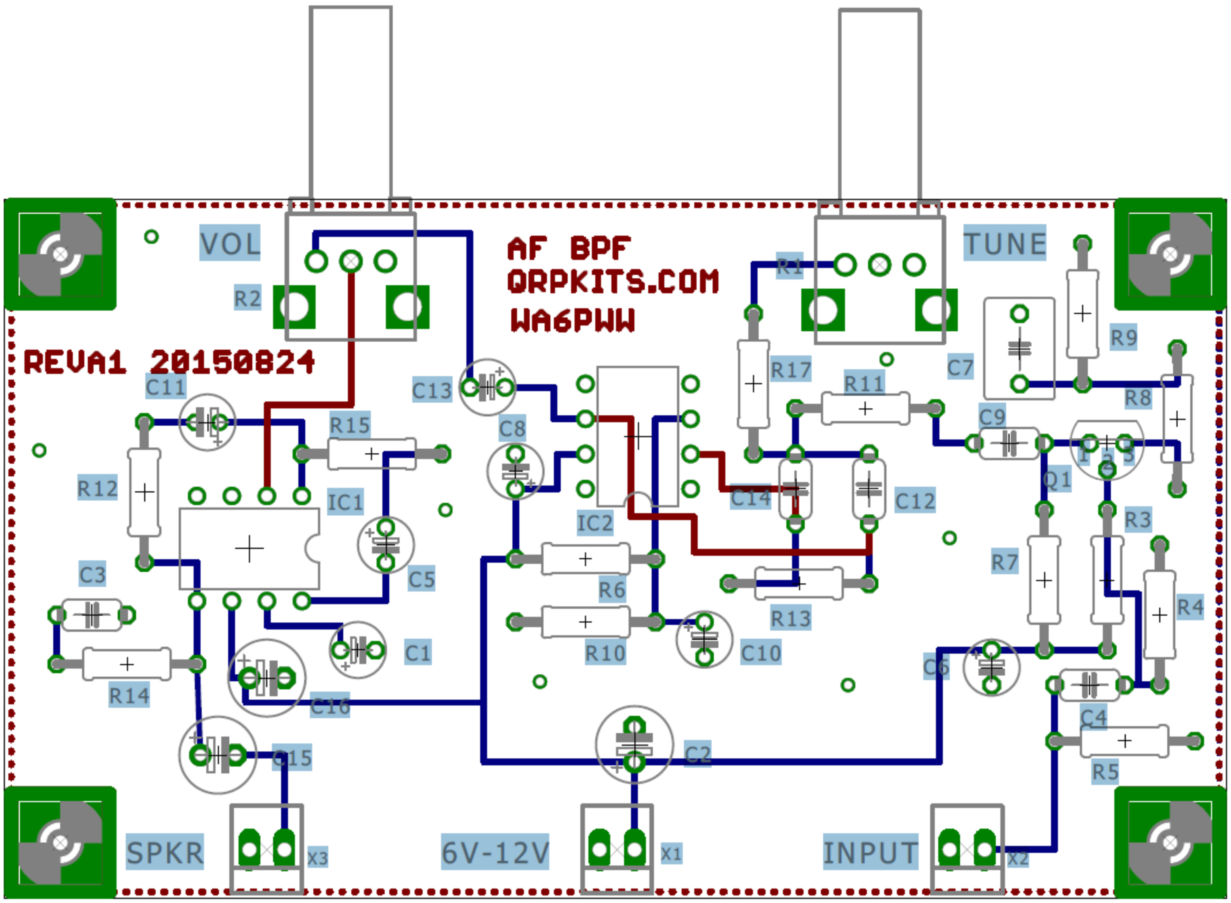
This is a simple kit and if assembled correctly, it should work without any problems but problems do occasionally happen.

If the kit fails to work, there are a few things to check.

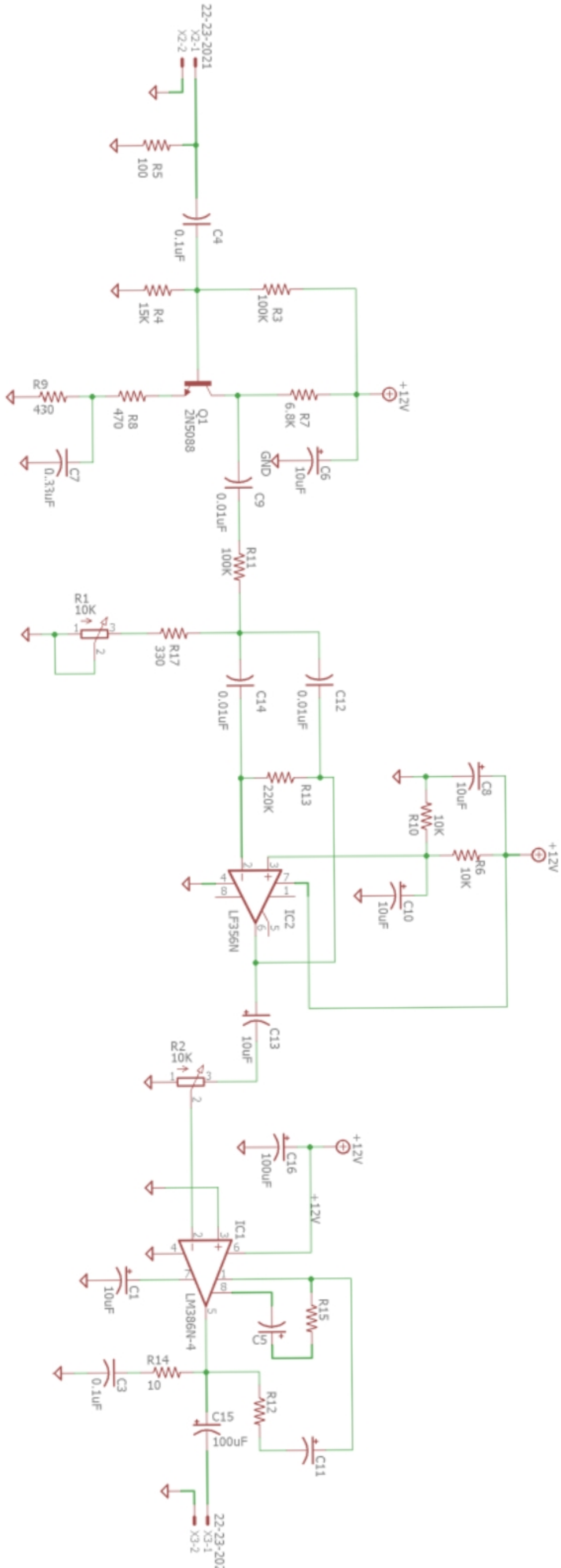
- Verify power supply voltage is at least 8V at the power input.
- Recheck component values, locations and orientations to be sure everything is installed correctly.
- Inspect the board for any missed solder joints, joints that may have not been heated sufficiently or for shorts between adjacent component pads.
- Reheat any suspect solder connections.
- Check input and output connectors for correct wiring.

If these tests do not resolve the problem, contact us at: qrpkits.com@gmail.com for further assistance.

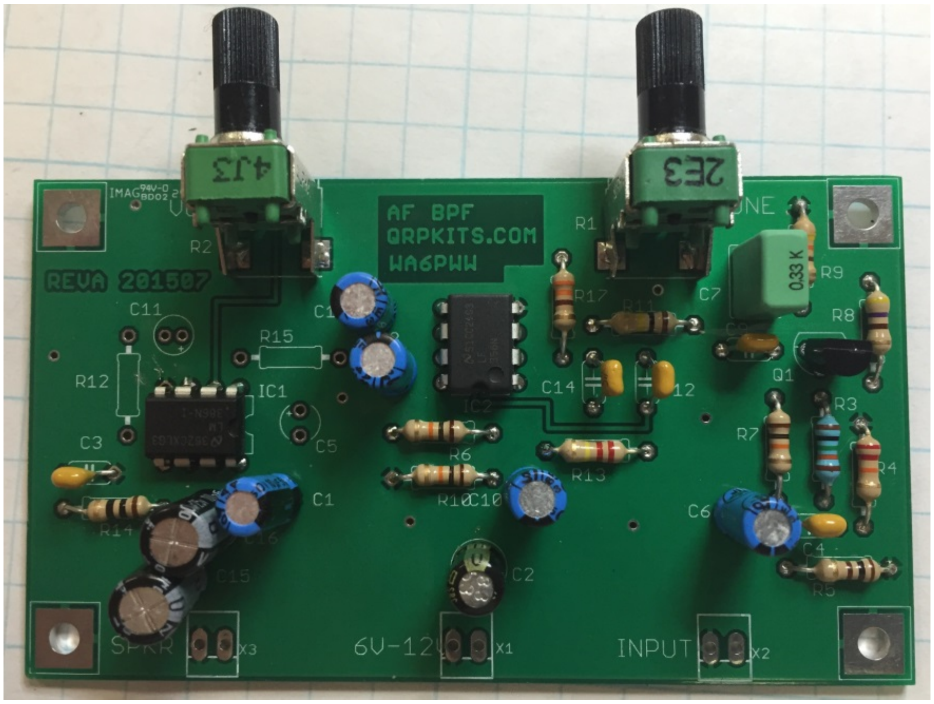
Board Layout



Schematic Diagram



Pacific Antenna Easy Audio Bandpass Filter Kit



Description and Specifications

The Audio Frequency Band Pass Filter kit from qrpkits.com provides A basic audio filter kit .

Incorporates a transistor preamp, op-amp based filter and an LM386 audio amplifier to drive headphones or speaker.

Has a peak in audio response that is tunable from approximately 300Hz to 2Khz

Has a bandwidth of approximately 500Hz.

Designed to provide improved audio filtering and amplification to CW reception or other devices that may not have sufficiently narrow bandwidth.

The kit may be powered from 9-12Vdc.

Support

PACIFIC ANTENNA
QRP KITS.COM
qrpkits.com@gmail.com

Tools Needed

- □ Temperature Controlled Soldering Station with small tip
  or 15-35 watt soldering iron with small tip.
- □ Solder 60/40 or 63/37 Tin-Lead
- □ Small Diagonal Cutters
- □ Small Needle Nose Pliers
- □ Pencil, Pen, and/or Highlighter
- □ BRIGHT work light

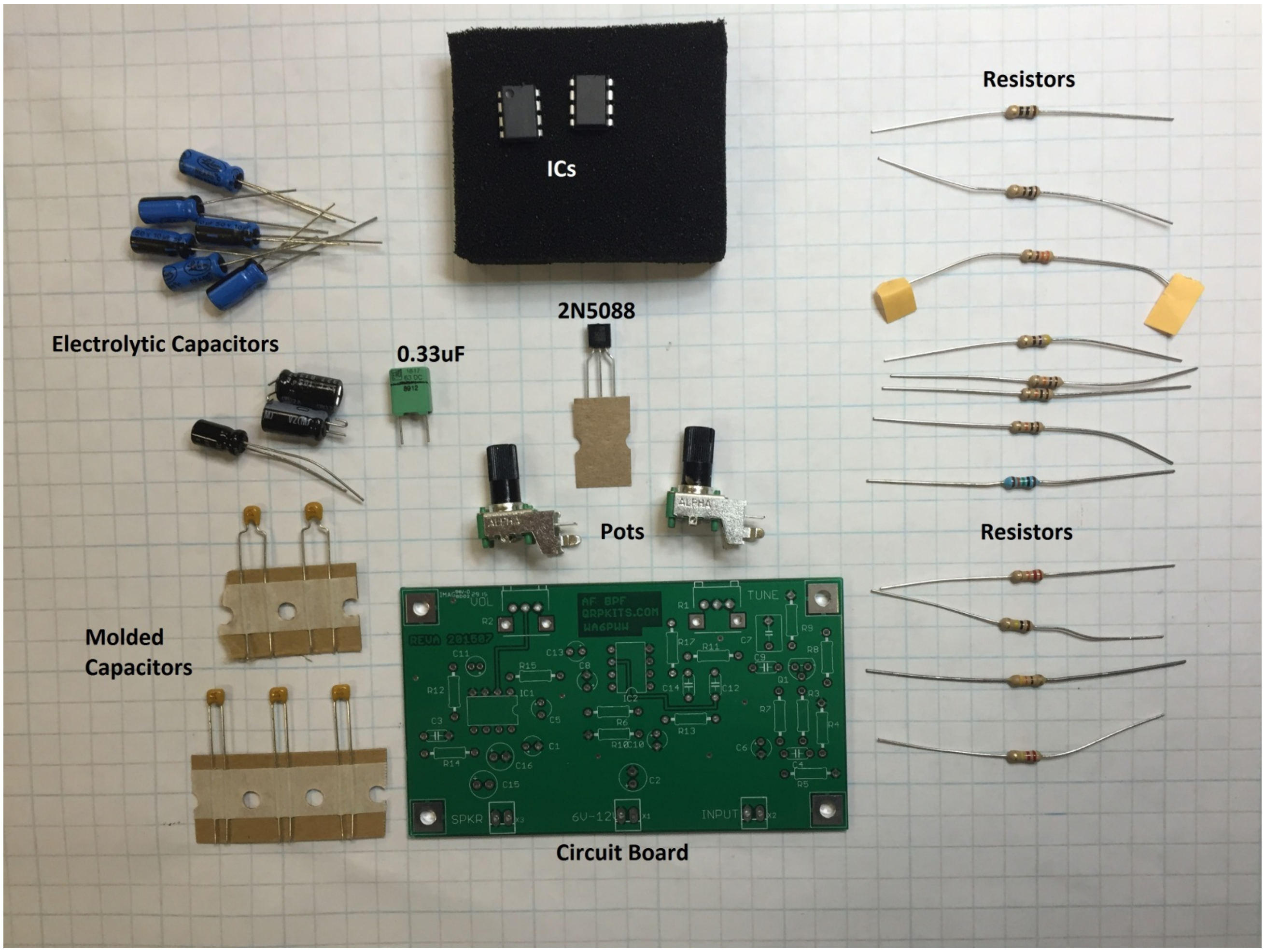
Optional

- □ Magnifying headpiece or lighted magnifying glass.
- □ Multi-meter
- □ Solder Sucker or Solder Wick
- □ Small multi-blade Screw Driver
- □ Knife or Wire Stripper
- □ Small Ruler
- □ Cookie Sheet to build in and keep parts from jumping onto the floor.

Construction Techniques

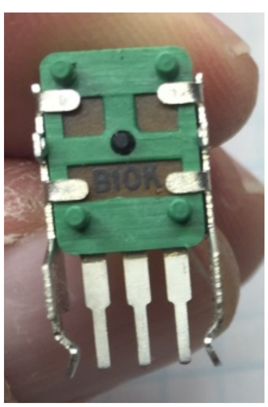
- □ There is no need to print out the whole assembly manual unless you want a copy. Print the Parts List and Schematic (last two pages) then view the rest of the manual on a computer, laptop, or tablet.
- □ The Parts List has columns for inventory and construction.
- □ Please take time to inventory the parts before starting. Report any shortages to QRPKITS.com (In many cases it may be faster and cheaper to pull a replacement from your parts supply, but please let us know if we missed something.)
- □ There is no need to print out the whole assembly manual unless you want a copy. Print the
- □ Pre-sorting the resistors and capacitors can speed up the assembly and reduce mistakes.
- □ You can insert several parts at a time onto the board. When you insert a part bend the leads over slightly to hold the part in place, then solder all at the same time. Clip the leads flush.
- □ Most parts should be mounted as close to the board as possible. Transistors should be mounted about 1/8" above the board. Solder one lead on ICs or IC sockets and then check to make sure the component is flush before soldering the remaining leads.
- □ Use a Temperature Controlled Soldering Station with small tip or 15-35 watt soldering iron with small tip. Conical or very small screw driver tips are best.
- □ DO NOT use a large soldering iron or soldering gun.
- □ If you are a beginner, new to soldering, there are a number of resources on the web to help you get on the right track soldering like a pro. Google Soldering Techniques. Here is one good example: http://www.elecraft.com/TechNotes/N0SS_SolderNotes/N0SS_SolderNotesV6.pdf

Parts Identification:

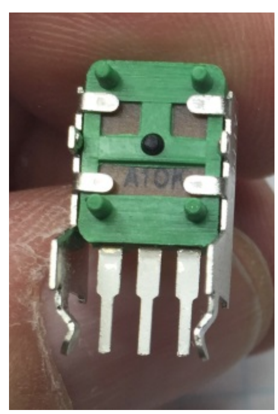


Note: This is a general guide. The parts supplied in the kit may vary slightly in appearance from those shown in this photo and not all parts included in the kit are shown.

Linear Potentiometer R1



Audio Potentiometer R2



Inventory and Parts List

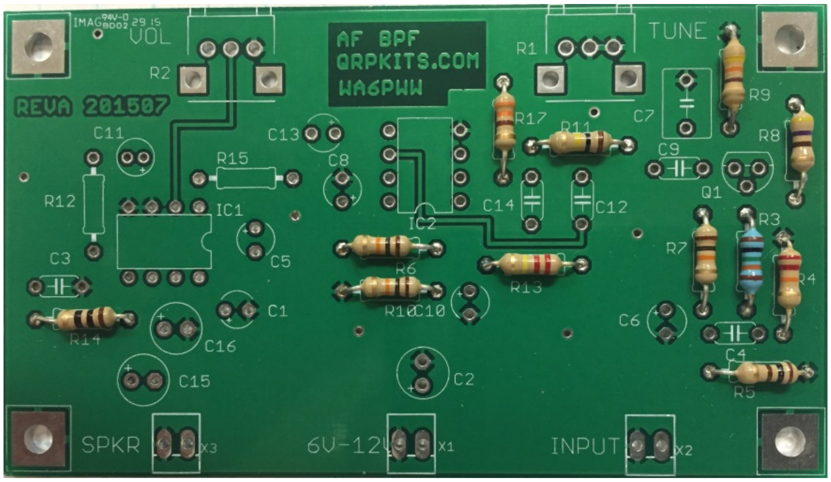
The first column is for inventory of parts and the second is to track as they are installed

Inventory	Installed	Part	Value	Identification	Description
		R14	10	Brn-blk-blk-gold	10 Ohm 1/4W resistor
		R5	100	Brn-blk-brn-gold	100 Ohm 1/4W resistor
		R17	330	Org-org-brn-gold	330 Ohm 1/4W resistor
		R9	430	Yel-org-brn-gold	430 Ohm 1/4W resistor
		R8	470	Yel-vio-brn-gold	470 Ohm 1/4W resistor
		R7	6.8K	Blu-gry-red-gold	6.8K Ohm 1/4W resistor
		R6	10K	Brn-blk-org-gold	10K Ohm 1/4W resistor
		R10	10K	Brn-blk-org-gold	10K Ohm 1/4W resistor
		R4	15K	Brn-grn-org-gold	15K Ohm 1`/4W resistor
		R3	100K	Brn-blk-yel-gold	100K Ohm 1/4W resistor
		R11	100K	Brn-blk-yel-gold	100K Ohm 1/4W resistor
		R13	220K	Red-red-yel-gold	22OK Ohm 1/4W resistor
*		R12	*Not Used		
*		R15	*Not Used		
		C9	0.01uF	103	Monolythic capacitor
		C12	0.01uF	103	Monolythic capacitor
		C14	0.01uF	103	Monolythic capacitor
		C3	0.1uF	104	Monolythic capacitor
		C4	0.1uF	104	Monolythic capacitor
		C7	0.33uF	0.33	Rectangular Film Capacitor
		C1	10uF	10uF electrolytic	Round can electrolytic capacitor
		C6	10uF	10uF electrolytic	Round can electrolytic capacitor
		C8	10uF	10uF electrolytic	Round can electrolytic capacitor
		C10	10uF	10uF electrolytic	Round can electrolytic capacitor
		C13	10uF	10uF electrolytic	Round can electrolytic capacitor
		C2	47uF	47uF electrolytic	Round can electrolytic capacitor
		C15	100uf	100uF electrolytic	Round can electrolytic capacitor
		C16	100uf	100uF electrolytic	Round can electrolytic capacitor
*		C5	*Not Used		
*		C11	*Not Used		
		Q1	2N5088	2N5088	Plastic, TO92 Transistor
		Socket	8 pin	8 Pin IC Socket	Black plastic socket for ICs
		Socket	8 pin	8 Pin IC Socket	Black plastic socket for ICs
		IC1	LM386	LM386	8 Pin IC
		IC2	LF356	LF356N	8 Pin IC
		R1	10K linear pot	B10K	9mm square rotary potentiometer
		R2	10K audio pot	A10K	9mm square rotary potentiometer
		Knob	Small Knob	black knob	Tuning knob
		Knob	Small Knob	black knob	Volume knob
		Connector	9V snap	9V battery connector	9V battery snap with leads
		Connector	3.5mm	Audio in	3.5mm audio jack
		Connector	3.5mm	Audio out	3.5mm audio jack
		Wire	3ft	Hookup wire	3 Colors 1 ft each
		PCB	Board	Circuit Board	AF BPF PCB Rev A1 or later

Inserting the Parts

Resistors

Sort the resistors by value insert them smallest value first, largest value last. There are 3 - 10K resistors and one of each of the others. Be sure to check the color code for each resistor as you install. [Measuring with an Ohm meter is a good idea.]



□	R14	10	brn-blk-blk-gold
□	R5	100	brn-blk-brn-gold
□	R17	330	org-org-brn-gold
□	R9	430	yel-org-brn-gold
□	R8	470	yel-vio-brn-gold
□	R6	10K	brn-blk-org-gold
□	R7	6.8K	blu-gry-red-gold
□	R10	10K	brn-blk-org-gold
□	R4	15K	brn-grn-org-gold
□	R11	100K	brn-blk-yel-gold
□	R3	100K	brn-blk-yel-gold
□	R13	220K	red-red-yel-gold

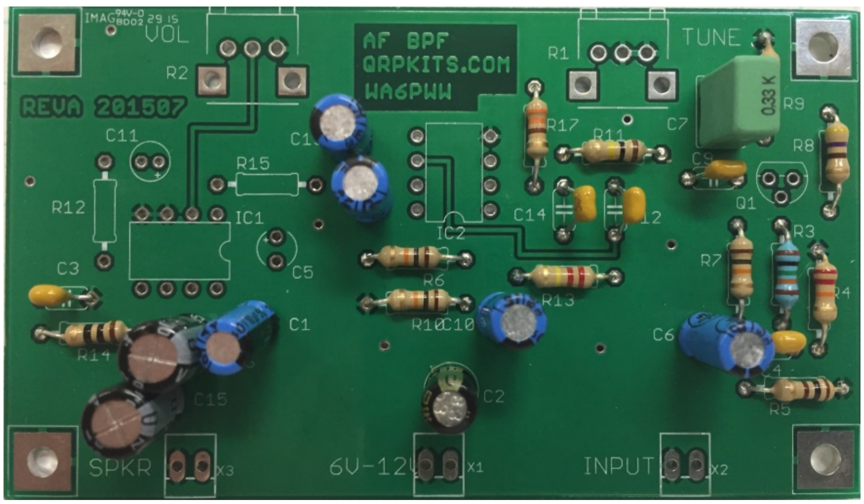
Capacitors

Next insert the molded capacitors. There are 3 - 0.01uF, 2 - 0.1uF, and 1 - 0.33uF. The 0.01uF and 0.1uF capacitors look very similar, double check the markings.

☐	C9	0.01uF	103
☐	C12	0.01uF	103
☐	C14	0.01uF	103
☐	C3	0.1uF	104
☐	C4	0.1uF	104
☐	C7	0.33uF	0.33K

Electrolytics

Now insert the electrolytic capacitors. These capacitors are polarized. The negative lead is marked with a black bar on the side of the capacitor.



☐	C1	10uF	10uF
☐	C6	10uF	10uF
☐	C8	10uF	10uF
☐	C10	10uF	10uF
☐	C13	10uF	10uF
☐	C2	47uF	47uF
☐	C15	100uF	100uF
☐	C16	100uF	100uF

Remaining Parts

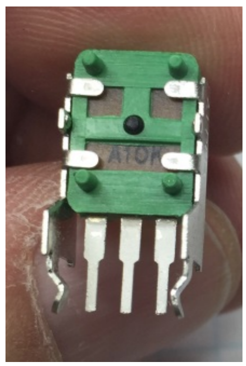
Now install Q1 the 2N5088 transistor. Follow the layout orientation on the board. The flat side of the transistor should match the flat side of the diagram.

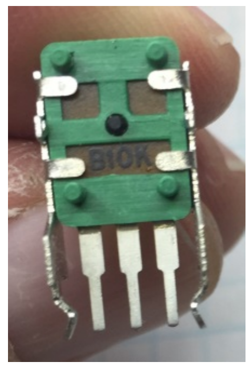
□ Q1 2N5088

Next install the two IC sockets and the ICs. Make sure the orientation notch on the IC matches the orientation notch on the circuit board.

□ IC1 LM386
□ IC2 LF356

The last 2 parts to install are the two potentiometers. The A10K and B10K identification marks are on the back of the pots and are a bit difficult to read. Use lots of light. Be sure that the B10K pot goes in the spot for R1 and the A10K goes in the location for R2 on the circuit board.





□ R1 10K Linear Pot (B) B10K
□ R2 10K Audio Pot (A) A10K

Hooking Up the Audio Frequency Band Pass Filter

The ABPF requires 8 - 12V DC. The power may be supplied from a companion kit, a small power supply, or a 9V battery using the battery clip that is included in the kit.
If using an AC operated supply, it should be well regulated and filtered to prevent hum or other noise being added to the audio. An inline fuse of 1A or less is recommended when an AC power supply or 12V battery is used.

Due to the many possible configurations, audio Input and output connections are also left up to the builder. The AFBPF may be wired directly into a receiver or speaker cabinet. Alternatively, the included jacks installed and 3.5mm plugs may be used for input and output connections. The kit is capable of directly driving a small speaker.

When the kit is first powered after assembly, it is recommended to use a battery or conenct an inline fuse or a power supply with the current limited to approximately 100-200mA to prevent damage if there are shorts. If you notice large power draw, stop and go back and inspect the board for any shorts or components installed incorrectly.

When the kit is first powered, you should hear static in the speaker or headphones that varies as the volume control is turned. If not, recheck the board for shorts and component errors.

If you have passed this step, you can connect an input audio signal from a receiver or other source of CW signals and you should hear the signal through the output. Moving the tuning knob will place the peak response on the chosen signal.

Packaging

Packaging is left up to the builder. The AFBPF can be built into another kit, or radio cabinet, installed in a speaker cabinet, or installed into a case.

Operation

R1 on the left side of the board is the tuning adjustment, tune to the desired listening frequency by peaking the audible sound on the chosen signal. This will have the affect of amplifying the desired signal while attenuating signals that differ in frequency.

R2 located on the right side of the board is the volume adjustment. Adjust for a comfortable listening level.

If the signals sound distorted, this is likely due to too much audio signal on the input. Reduce the input audio level from the source until the signals sound clean.

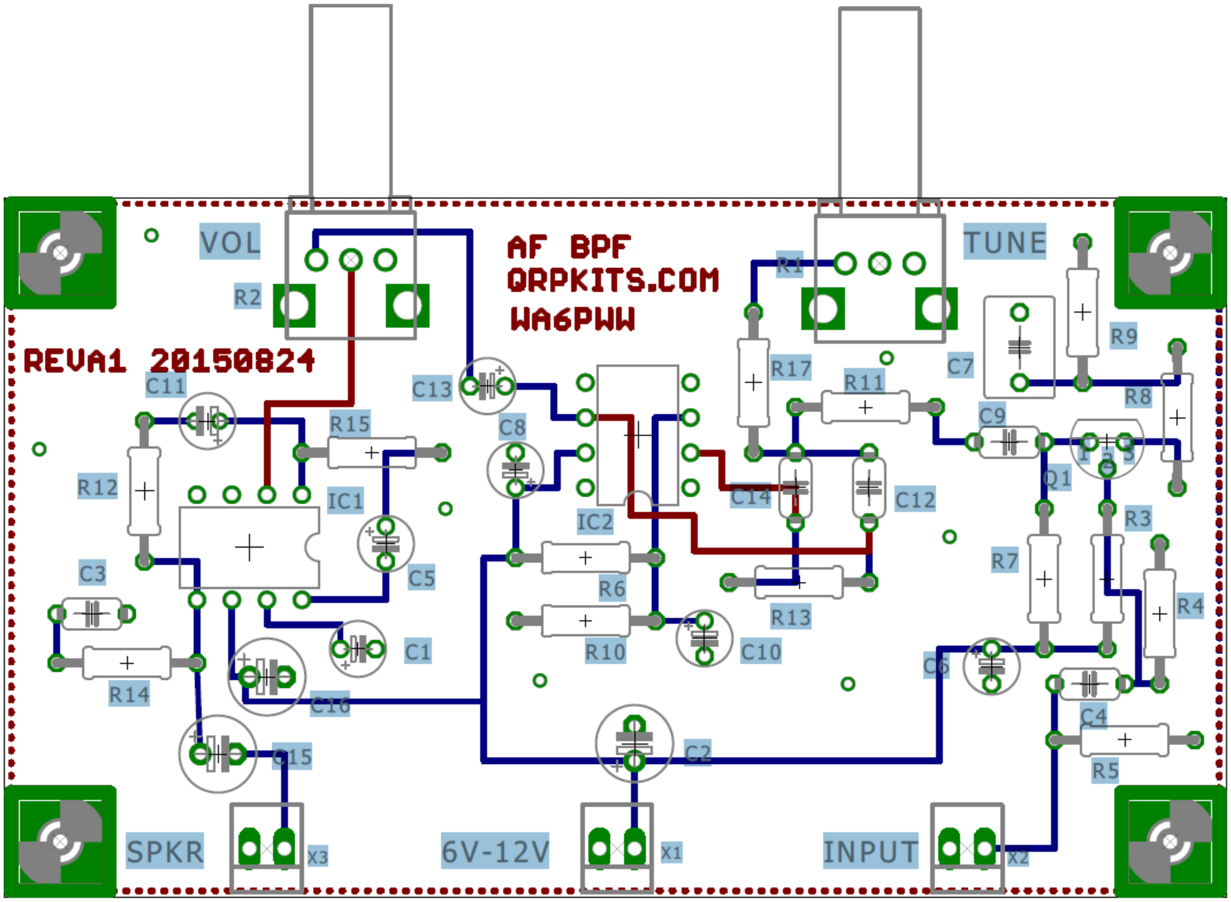
Troubleshooting

This is a simple kit and if assembled correctly, it should work without any problems but problems do occasionally happen.

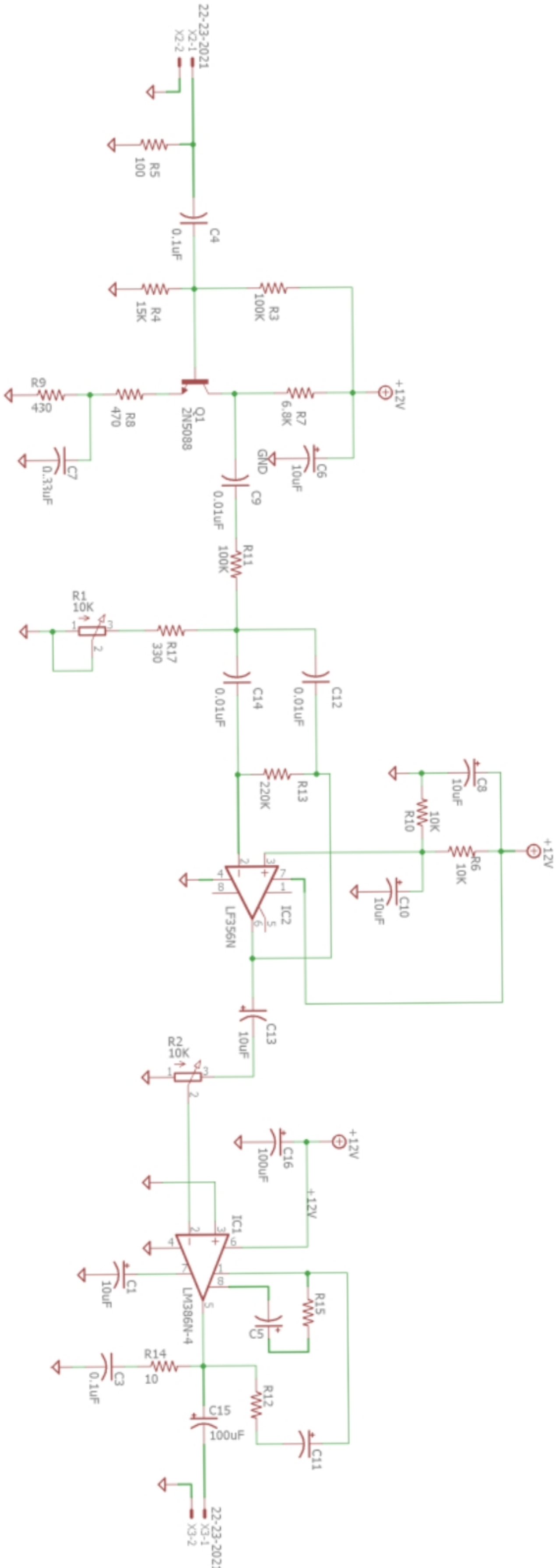
If the kit fails to work, there are a few things to check.

- Verify power supply voltage is at least 8V at the power input.
- Recheck component values, locations and orientations to be sure everything is installed correctly.
- Inspect the board for any missed solder joints, joints that may have not been heated sufficiently or for shorts between adjacent component pads.
- Reheat any suspect solder connections.
- Check input and output connectors for correct wiring.

If these tests do not resolve the problem, contact us at: qrpkits.com@gmail.com for further assistance.


VOL
R2
AF BPF
QRPKITS.COM
WA6PWW
R1
TUNE
R9
R17
R11
C7
REVA1 20150824
C11
C13
R8
R15
C8
C9
R12
IC1
IC2
C14
C12
Q1
R3
C3
C5
R6
R7
R13
R4
C1
R10
C10
R14
C16
C6
C4
C2
C15
R5
SPKR
X3
6V-12V
X1
INPUT
X2

Schematic Diagram



Types of Diodes

JANUARY 27, 2015 BY ADMINISTRATOR — 21 COMMENTS

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Introduction

Diodes are electronic components functions as a one-way valve it means it allow current to flow in one direction. These diodes are manufactured by the semiconductor materials germanium, silicon and selenium. Operation of diode can be classified in two ways, if it allows the current then it is forward biased otherwise it is reverse biased.

For silicon diodes the forward voltage is 0.7v and for germanium it is 0.3v. In silicon diode the dark band indicates the cathode terminal and the other terminal is anode. Generally diodes are used as reverse polarity protector and transient protector. There are many types of diodes and some of these are listed as follows.

1. Small Signal Diode

It is a small device with disproportional characteristics and whose applications are mainly involved at high frequency and very low currents devices such as radios and televisions etc. To protect the diode from contamination it is enveloped with a glass so it is also named as Glass Passivated Diode which is extensively used as 1N4148.

The appearance of signal diode is very small when compared with the power diode. To indicate the cathode terminal one edge is marked with black or red in color. For the applications at high frequencies the performance of the small signal diode is very effective.

With respect to the functional frequencies of the signal diode the carrying capacity of the current and power are very low which are maximum nearly at 150mA and 500mW.

The signal diode is a silicon doped semiconductor diode or a germanium doped diode but depending up on the doping material the characteristics of the diode varies. In signal diode the characteristics of the silicon doped diode is approximately opposite to the germanium doped diode.

The silicon signal diode has high voltage drop at the coupling about 0.6 to 0.7 volts so, it has very high resistance but low forward resistance. On other hand germanium signal diode has low resistance due to low voltage drop nearly at 0.2 to 0.3 volts and high forward resistance. Due to small signal the functional point is not disrupted in small signal diode.

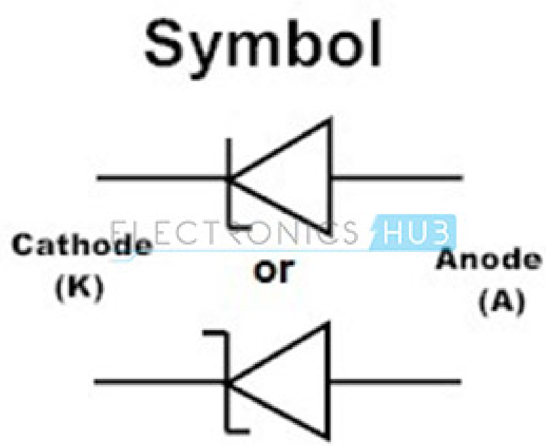
2. Large Signal Diode

These diodes have large PN junction layer. Thus the transformation of AC to DC voltages is unbounded. This also increases the current forward capacity and reverse blocking voltage. These large signals will disrupt the functional point also. Due to this it is not suitable for high frequency applications.

The main applications of these diodes are in battery charging devices like inverters. In these diodes the range of forward resistance is in Ohms and the reverse blocking resistance is in mega Ohms. Since it has high current and voltage performance these can be used in electrical devices which are used to suppress high peak voltages.

3. Zener Diode

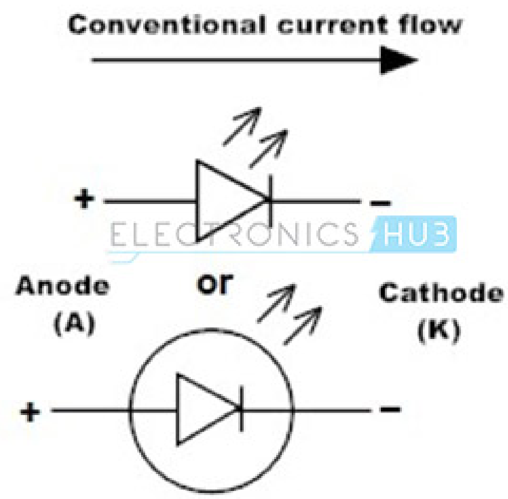
It is a passive element works under the principle of zener breakdown. First produced by Clarence zener in 1934.It is similar to normal diode in forward direction, it also allows current in reverse direction when the applied voltage reaches the breakdown voltage. It is designed to prevent the other semiconductor devices from momentary voltage pulses. It acts as voltage regulator.



4. Light Emitting Diode (LED)

These diodes convert the electrical energy in to light energy. First production started in 1968. It undergoes electroluminescence process in which holes and electrons are recombined to produce energy in the form of light in forward bias condition.

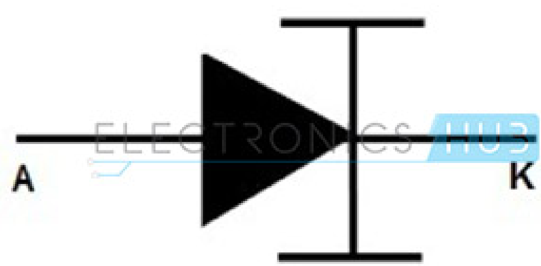
Earlier they used in inductor lamps but now in recent applications they are using in environmental and task handling. Mostly used in applications like aviation lighting, traffic signals, camera flashes.



5. Constant Current Diodes

It is also known as current-regulating diode or constant current diode or current-limiting diode or diode-connected transistor. The function of the diode is regulating the voltage at a particular current.

It functions as a two terminal current limiter. In this JFET acts as current limiter to achieve high output impedance. The constant current diode symbol is shown below.

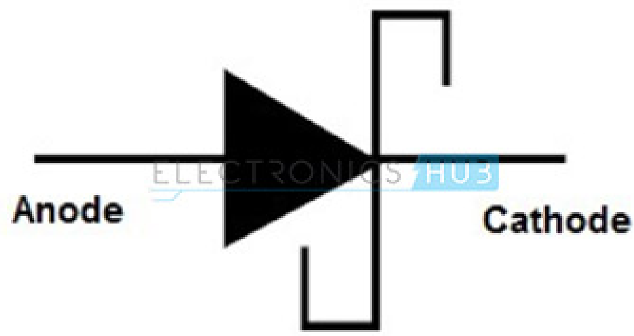


6. Schottky Diode

In this type of diode the junction is formed by contacting the semiconductor material with metal. Due to this the forward voltage drop is decreased to min. The semiconductor material is N-type silicon which acts as an anode and the metal acts as a cathode whose materials are chromium, platinum, tungsten etc.

Due to the metal junction these diodes have high current conducting capability thus the switching time reduces. So, Schottky has greater use in switching applications. Mainly because of the metal- semiconductor junction the voltage drop is low which in turn increase the diode

performance and reduces power loss. So, these are used in high frequency rectifier applications. The symbol of Schottky diode is as shown below.

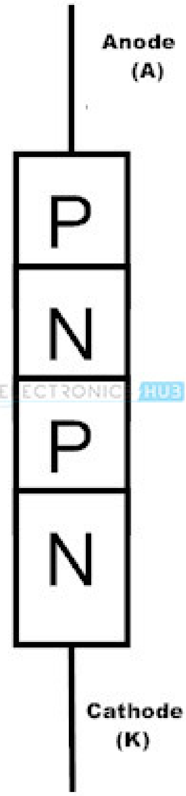


Applications	Purpose
Voltage clamping	To prevent transistor from saturation this is possible due to the higher current density of schottky diode
Reverse current and discharge protection	It prevents the reverse currents and helps the batteries to discharge
Power supply	Acts as rectifier

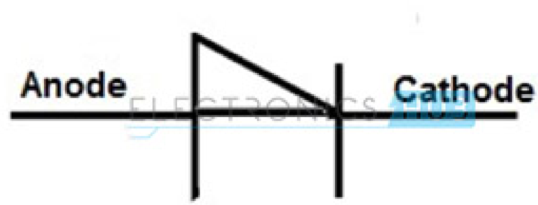
7. Shockley Diode

It was the invention of first semiconductor devices it has four layers. It is also called as PNPN diode. It is equal to a thyristor without a gate terminal which means the gate terminal is disconnected. As there is no trigger inputs the only way the diode can conduct is by providing forward voltage.

It stays on one's it turned "ON" and stays off one's it turned "OFF". The diode has two operating states conducting and non-conducting. In non-conducting state the diode conducts with less voltage.



The symbol of the Shockley diode is as follows:



Shockley Diode Applications

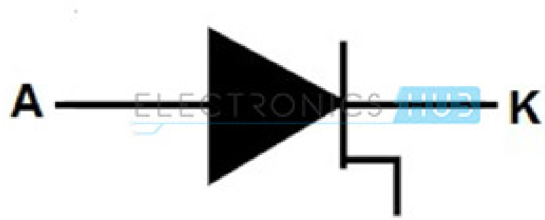
- Trigger switches for SCR.
- Acts as relaxation oscillator.

8. Step Recovery Diodes

It is also called as snap-off diode or charge-storage diode. These are the special type of diodes which stores the charge from positive pulse and uses in the negative pulse of the sinusoidal signals. The rise time of the current pulse is equal to the snap time. Due to this phenomenon it has speed recovery pulses.

The applications of these diodes are in higher order multipliers and in pulse shaper circuits. The cut-off frequency of these diodes is very high which are nearly at Giga hertz order.

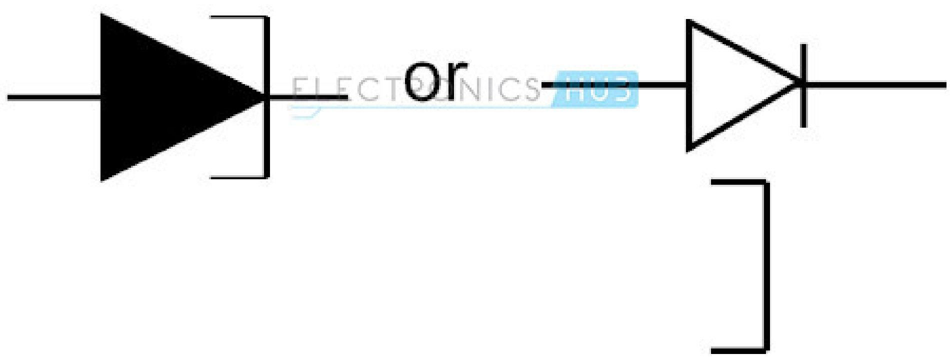
As multiplier this diode has the cut-off frequency range of 200 to 300 GHz. In the operations which are performing at 10 GHz range these diodes plays a vital role. The efficiency is high for lower order multipliers. The symbol for this diode is as shown below.



Tunnel Diode

It is used as high speed switch, of order nano-seconds. Due to tunneling effect it has very fast operation in microwave frequency region. It is a two terminal device in which concentration of dopants is too high.

The transient response is being limited by junction capacitance plus stray wiring capacitance. Mostly used in microwave oscillators and amplifiers. It acts as most negative conductance device. Tunnel diodes can be tuned in both mechanically and electrically. The symbol of tunnel diode is as shown below.



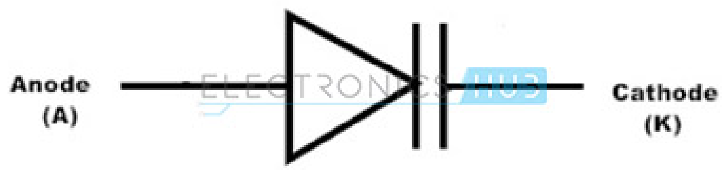
Tunnel Diode Applications

1. Oscillatory circuits.
2. Microwave circuits.
3. Resistant to nuclear radiation.

10. Varactor Diode

These are also known as Varicap diodes. It acts like the variable capacitor. Operations are performed mainly at reverse bias state only. These diodes are very famous due to its capability of changing the capacitance ranges within the circuit in the presence of constant voltage flow.

They can able to vary capacitance up to high values. In varactor diode by changing the reverse bias voltage we can decrease or increase the depletion layer. These diodes have many applications as voltage controlled oscillator for cell phones, satellite pre-filters etc. The symbol of varactor diode is given below.



Varactor Diode Applications

1. Voltage-controlled capacitors.
2. Voltage-controlled oscillators.
3. Parametric amplifiers.
4. Frequency multipliers.
5. FM transmitters and Phase locked loops in radio, television sets and cellular telephone.

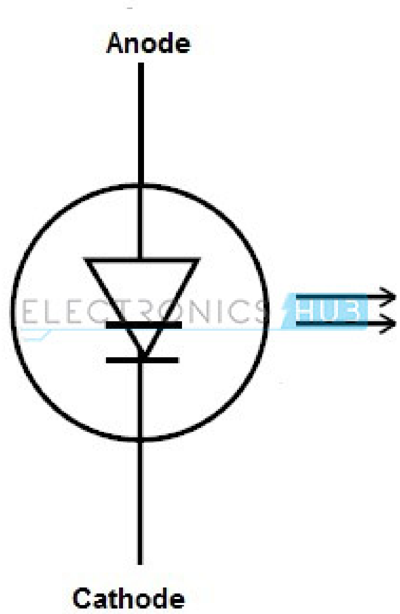
11. Laser Diode

Similar to LED in which active region is formed by p-n junction. Electrically laser diode is p-i-n diode in which the active region is in intrinsic region. Used in fiber optic communications, barcodereaders, laser pointers, CD/DVD/Blu-ray reading and recording, Laser printing.

Laser Diode Types:

1. **Double Heterostructure Laser:** Free electrons and holes available simultaneously in the region.
2. **Quantum Well Lasers:** lasers having more than one quantum well are called multi quantum well lasers.
3. **Quantum Cascade Lasers:** These are heterojunction lasers which enables laser action at relatively long wavelengths.
4. **Separate Confinement Heterostructure Lasers:** To compensate the thin layer problem in quantum lasers we go for separate confinement heterostructure lasers.
5. **Distributed Bragg Reflector Lasers:** It can be edge emitting lasers or VCSELS.

The symbol of the Laser Diode is as shown:



12. Transient Voltage Suppression Diode

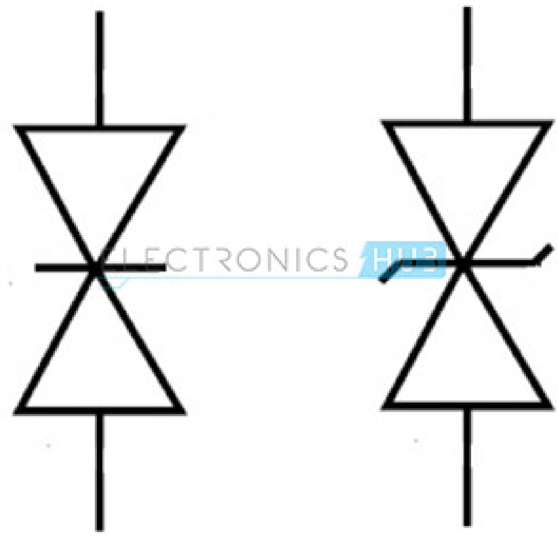
In semiconductor devices due to the sudden change in the state voltage transients will occur. They will damage the device output response. To overcome this problem voltage suppression diode diodes are used. The operation of voltage suppression diode is similar to Zener diode operation.

The operation of these diodes is normal as p-n junction diodes but at the time of transient voltage its operation changes. In normal condition the impedance of the diode is high. When any transient voltage occurs in the circuit the diode enters in to the avalanche breakdown region in which the low impedance is provided.

It is spontaneously very fast because the avalanche breakdown duration ranges in Pico seconds. Transient voltage suppression diode will clamp the voltage to the fixed levels, mostly its clamping voltage is in minimum range.

These are having applications in the telecommunication fields, medical, microprocessors and signal processing. It responds to over voltages faster than varistors or gas discharge tubes.

The symbol for Transient voltage suppression diode is as shown below.



The diode is characterized by

- Leakage current
- Maximum reverse stand-off voltage
- Breakdown voltage
- Clamping voltage
- Parasitic capacitience
- Parasitic inductance
- Amount of energy it can absorb

13. Gold Doped Diodes

In these diodes gold is used as a dopant. These diodes are faster than other diodes. In these diodes the leakage current in reverse bias condition also less. Even at the higher voltage drop it allows the diode to operate in signal frequencies. In these diodes gold helps for the faster recombination of minority carriers.

14. Super Barrier Diodes

It is a rectifier diode having low forward voltage drop as schottky diode with surge handling capability and low reverse leakage current as p-n junction diode. It was designed for high power, fast switching and low-loss applications. Super barrier rectifiers are the next generation rectifiers with low forward voltage than schottky diode.

15. Peltier Diode

In this type of diode, at the two material junction of a semiconductor it generates a heat which flows from one terminal to another terminal. This flow is done in only single direction that is as equal to the direction of current flow.

This heat is produced due to electric charge produced by the recombination of minority charge carriers. This is mainly used in cooling and heating applications. This type of diodes used as sensor and heat engine for thermo electric cooling.

16. Crystal Diode

This is also known as Cat's whisker which is a type of point contact diode. Its operation depends on the pressure of contact between semiconductor crystal and point.

In this a metal wire is present which is pressed against the semiconductor crystal. In this the semiconductor crystal acts as cathode and metal wire acts as anode. These diodes are obsolete in nature. Mainly used in microwave receivers and detectors.

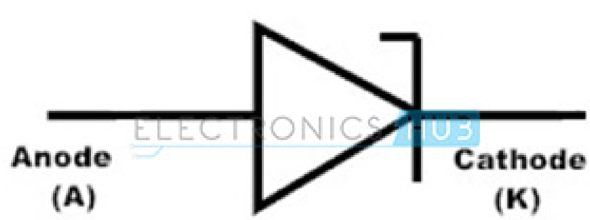
Crystal Diode Applications

1. Crystal diode rectifier
2. Crystal diode detector
3. Crystal radio receiver

17. Avalanche Diode

This is passive element works under principle of avalanche breakdown. It works in reverse bias condition. It results large currents due to the ionisation produced by p-n junction during reverse bias condition.

These diodes are specially designed to undergo breakdown at specific reverse voltage to prevent the damage. The symbol of the avalanche diode is as shown below:

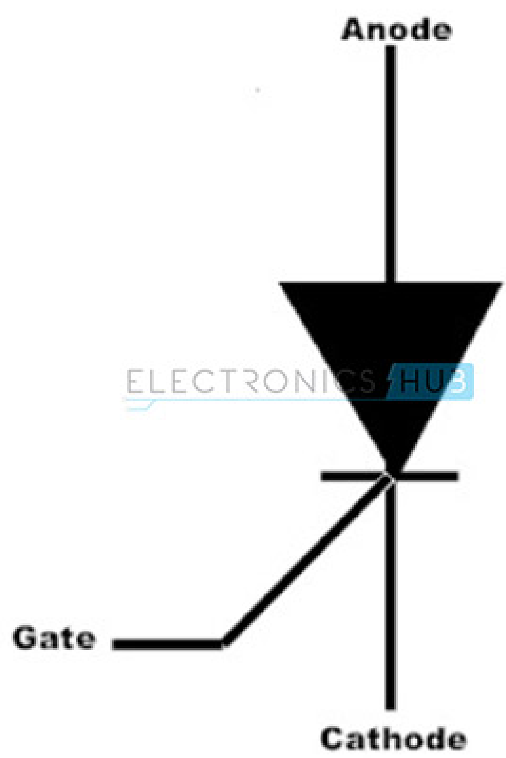


Avalanche Diode Uses

1. **RF Noise Generation:** It acts as source of RF for antenna analyzer bridges and also as white noise generators. Used in radio equipments and also in hardware random number generators.
2. **Microwave Frequency Generation:** In this the diode acts as negative resistance device.
3. **Single Photon Avalanche Detector:** These are high gain photon detectors used in light level applications.

18. Silicon Controlled Rectifier

It consists of three terminals they are anode, cathode and a gate. It is nearly equal to the Shockley diode. As its name indicates it is mainly used for the control purpose when small voltages are applied in the circuit. The symbol of the Silicon Controlled Rectifier is as shown below:



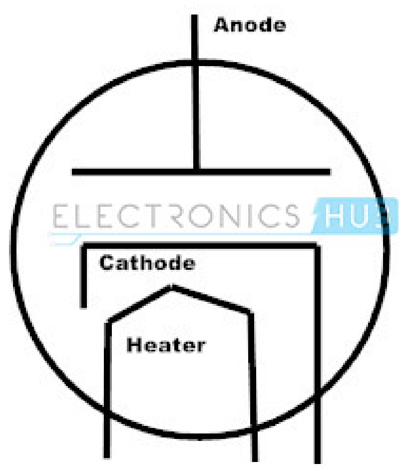
Modes of Operation:

1. Forward blocking mode (off state): In this j1 and j3 forward biased and j2 is reverse biased. It offers high resistance below breakover voltage and hence it is said to be off state.
2. Forward conduction mode (on state): By increasing the voltage at anode and cathode or by applying positive pulse at the gate we can turn ON. To turn off the only way is to decrease the current flowing through it.
3. Reverse blocking mode (off state): SCR blocking the reverse voltage is named as asymmetrical SCR. Mostly used in current source inverters.

19. Vacuum Diodes

Vacuum diodes consist of two electrodes which will acts as an anode and the cathode. Cathode is made up of tungsten which emits the electrons in the direction of anode. Always electron flow will be from cathode to anode only. So, it acts like a switch.

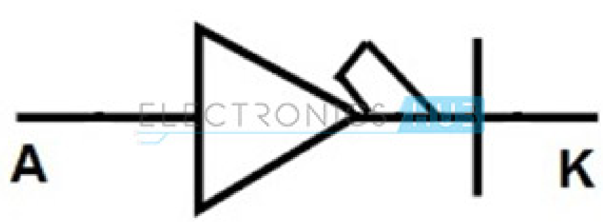
If the cathode is coated with oxide material then the electrons emission capability is high. Anode is a bit long in size and in some cases their surface is rough to reduce the temperatures developing in the diode. The diode will conduct in only one case that is when the anode is positive regarding to cathode terminal. The symbol is as shown in figure:



20. PIN Diode

The improved version of the normal P-N junction diode gives the PIN diode. In PIN diode doping is not necessary. The intrinsic material means the material which has no charge carriers is inserted between the P and N regions which increase the area of depletion layer.

When we apply forward bias voltage the holes and electrons will pushed into the intrinsic layer. At some point due to this high injection level the electric field will conduct through the intrinsic material also. This field made the carriers to flow from two regions. The symbol of PIN diode is as shown below:

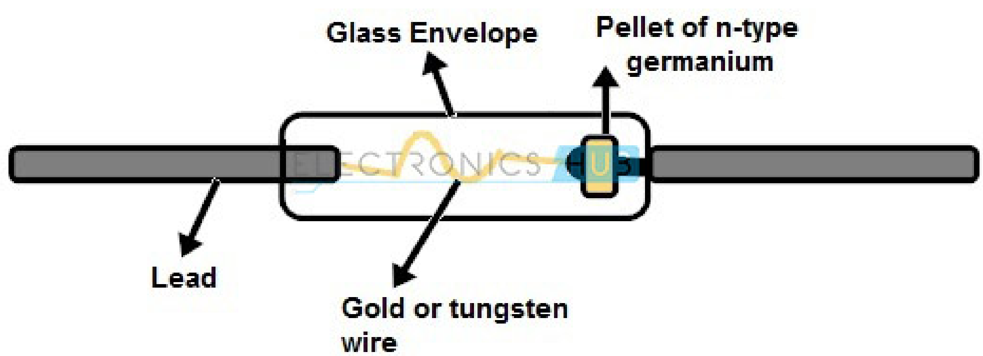


PIN Diode Applications:

1. **Rf Switches:** Pin diode is used for both signal and component selection. For example pin diodes acts as range-switch inductors in low phase noise oscillators.
2. **Attenuators:** it is used as bridge and shunt resistance in bridge-T attenuator.
3. **Photo Detectors:** it detects x-ray and gamma ray photons.

21. Point Contact Devices

A gold or tungsten wire is used to act as the point contact to produce a PN junction region by passing a high electric current through it. A small region of PN junction is produced around the edge of the wire which is connected to the metal plate which is as shown in the figure.

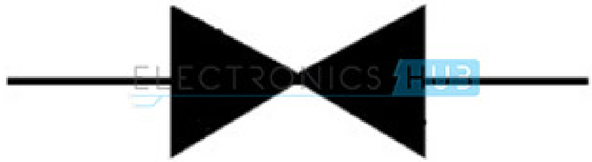


In forward direction its operation is quite similar but in reverse bias condition the wire acts like an insulator. Since this insulator is between the plates the diode acts as a capacitor. In general the capacitor blocks the DC currents when the AC currents are flowing in the circuit at high frequencies. So, these are used to detect the high frequency signals.

22. Gunn Diode

Gunn diode is fabricated with n-type semiconductor material only. The depletion region of two N-type materials is very thin. When voltage increases in the circuit the current also increases. After certain level of voltage the current will exponentially decrease thus this exhibits the negative differential resistance.

It has two electrodes with Gallium Arsenide and Indium Phosphide due to these it has negative differential resistance. It is also termed as transferred electron device. It produces micro wave RF signals so it is mainly used in Microwave RF devices. It can also use as an amplifier. The symbol of Gunn diode is shown below:



PREVIOUS – DIODE CHARACTERISTICS

NEXT – SIGNAL DIODE TUTORIAL

FILED UNDER: DIODES

Comments

akash says

NOVEMBER 24, 2015 AT 9:45 AM

Zener diode nai hai isme

Reply

Ranajit says
APRIL 9, 2017 AT 8:52 PM

no 3 is zener diode

Reply

naresh says
DECEMBER 31, 2015 AT 2:24 AM

thank q for best information

Reply

Sdk says
FEBRUARY 9, 2016 AT 11:54 AM

Thank u frnd

Reply

cutie says
FEBRUARY 16, 2016 AT 9:29 PM

Thank u for this useful information

Reply

Chalew Cheru says
JUNE 30, 2016 AT 6:46 AM

Thank you very much. you help several people specially students

Reply

Shaik mubeena says
JULY 19, 2016 AT 9:59 PM

Thank u

Reply

keshi says
AUGUST 31, 2016 AT 9:16 PM

Thanks a lot more bless

Reply

khan says
SEPTEMBER 29, 2016 AT 11:55 AM

realy , very informable.....

Reply

laugh like hell says
MARCH 19, 2017 AT 8:31 AM

this is a hard core electronics

Reply

megha says

APRIL 8, 2017 AT 2:24 PM

Thanku so much for such a brief and valuable information…

Reply

charles says

JULY 5, 2017 AT 10:15 AM

thank you very much your info

Reply

vanita says

AUGUST 19, 2017 AT 2:27 AM

provide a picture with a info if possible

Reply

vanita says

AUGUST 19, 2017 AT 2:29 AM

provide a picture with info if possible.it can betterly understand

Reply

Saranga says
AUGUST 25, 2017 AT 3:42 PM

Very useful information. Thank you very much.

Reply

frank wobil says
SEPTEMBER 25, 2017 AT 8:31 AM

thanks for the information

Reply

Saket says
OCTOBER 6, 2017 AT 2:42 PM

It is very very important information to learn about different types of semiconductors……

Reply

Jyoti prakash says
NOVEMBER 17, 2017 AT 2:57 PM

very important information about the diodes

Reply

ntulume yassini luyimbazi says
DECEMBER 7, 2017 AT 7:24 AM

thanks dia

Reply

Abdullahi OkinG says
DECEMBER 16, 2017 AT 1:49 AM

thank you very much for you explain diodes

Reply

Rohit says
JANUARY 8, 2018 AT 3:55 PM

Its very helpful

Reply

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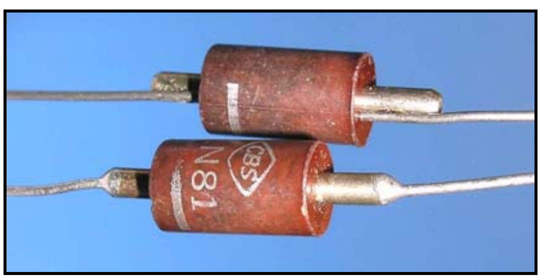
TRANSISTOR MUSEUM™

HISTORY OF CRYSTAL DIODES

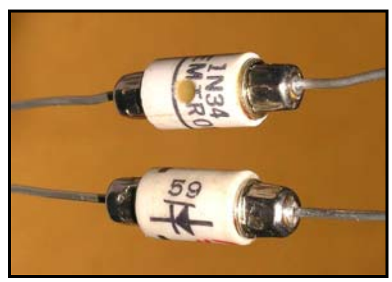
VOLUME 1
1950s GERMANIUM RADIO DETECTORS

Special Collection of Historic Diodes Designed for the Historian, Engineer, Experimenter, Researcher and Hobbyist

INCLUDED ARE CLASSIC EXAMPLES OF EACH OF THESE HISTORIC 1950s GERMANIUM DIODES:



CBS 1N81



KEMTRON 1N34

SYLVANIA 1N34A

A Publication of the Transistor Museum™

ABOUT YOUR HISTORIC GERMANIUM CRYSTAL DIODES

Crystal diode technology can be traced back to the early 1900s, when hand-adjusted silicon detectors were first used with the new wireless devices to detect radio signals. Within a few years germanium/galena "cat-whiskers" were being used by amateur radio enthusiasts and in early commercial radios. Vacuum tube detectors largely replaced the use of these early crystal diode devices in most applications, until the widespread use of radar in WW II required high frequency, low noise detector/mixer diodes. Millions of silicon crystal diodes, such as the 1N21, were manufactured in the 1940s for military radar use. Sylvania pioneered the use of germanium for diodes, with the introduction in 1946 of the 1N34 – the first commercial germanium crystal diode.

Volume 1 of **The History of Crystal Diodes** includes historic examples of three germanium crystal diode types which are similar in performance and construction to the original 1N34. Below is a summary of the included diodes:

KEMTRON 1N34: From the 1950s, this ceramic-cased 1N34 represents a close copy of the original 1N34 from Sylvania. Of additional importance is the fact that KEMTRON is a little-known but historically significant diode company.

Sylvania 1N34A: From the 1940s and 1950s, the 1N34A represents a major advance by Sylvania in diode technology, and that is the use of a hermetically-sealed glass case for the device. This approach is still in use today.

CBS/Hytron 1N81: From the 1950s, the 1N81 is a unique device, manufactured by a major company (CBS) that was very active in mid-century semiconductor work, but exited the business in the early 1960s. The brown plastic case style of the 1N81 represents an early, but short-lived diode technology that was obsolete within a few years.

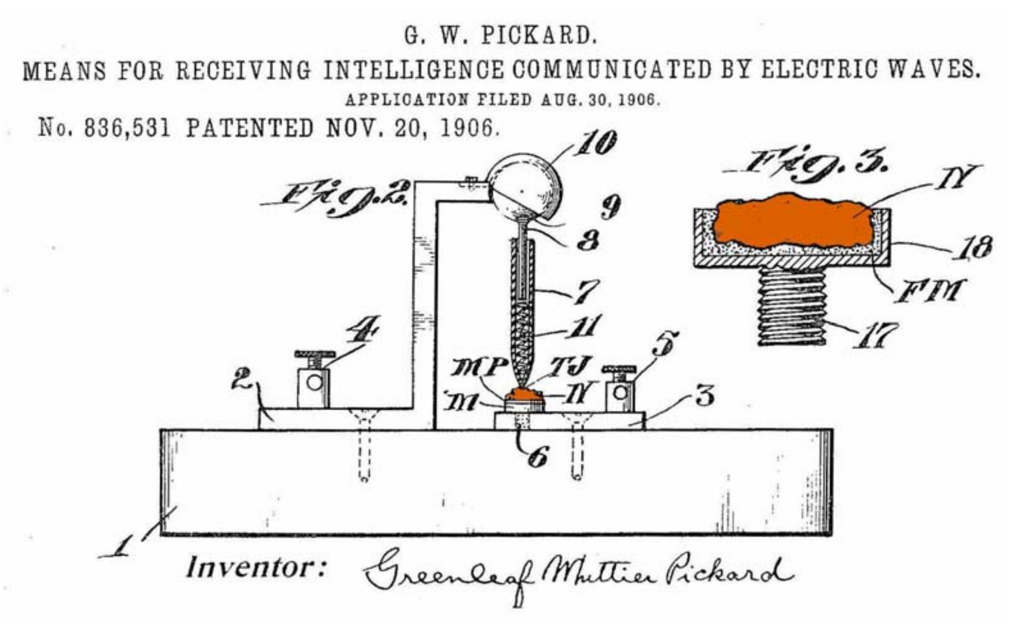
You'll receive one of each type above, supplied in a display package with appropriate labeling. All the diodes are clearly marked with type identification numbers and are vintage 1950s. Your diodes have been tested and function electrically as diodes, and should perform as designed in original circuit applications such as crystal radio circuits. However, due to the possible effects of age and storage conditions, no guarantees can be made about overall device performance.

The Transistor Museum™ is a virtual museum that has been developed to help preserve the history of the greatest invention of the 20TH century – the TRANSISTOR. Please visit the museum at: http://www.transistormuseum.com

THE FIRST CRYSTAL DETECTORS

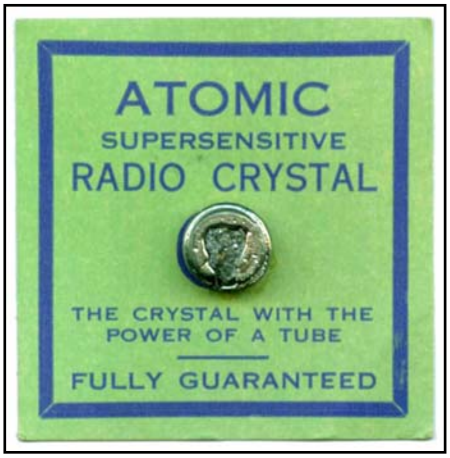
One of the earliest patents for crystal detector technology was granted in 1906 to Mr. G.W. Pickard of Amesbury, Massachusetts. A section of this patent (#836531) is shown below. As stated in this patent, "The invention relates to means for receiving intelligence communicated by electric waves". Further explanation by Mr. Pickard provides a clear description of the construction and operation of what would soon be known as the "cat's whisker" crystal detector. For several decades, into the 1930s, 1940s and 1950s, the cat's whisker crystal detector was used by radio manufacturers and electronics hobbyists as a key component in radio circuits. (See reference **[1]** for Tom Lee's excellent article, which provides a detailed discussion of early crystal diode technology. Also see references **[2]** and **[3]**).

Although the cat's whisker crystal detector could be made to operate, there were some basic limitations with this device that limited its continued and widespread use. As described in the Pickard patent, and further illustrated below, the crystal detector required manual adjustment of a mechanical point (the "cat's whisker") that was pressed down on to a crystal, and then was adjusted to find a "hot spot" on the crystal that provided the best radio wave detection. The sharp point of the "cat's whisker" would sometimes physically move out of the best performance area of the crystal, and would require frequent re-adjustment. Because of the erratic performance of the cat's whisker, commercial radio companies began using vacuum tube diode detectors in the 1920s and the cat's whisker remained primarily as an historical curiosity and hobbyist device.

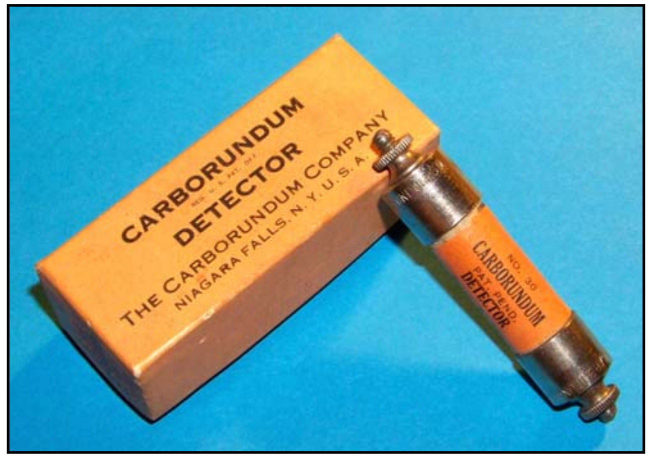


Shown above is a section of G.W. Pickard's 1906 patent of a silicon crystal (Fig 3) used with a metal spring-loaded "cat's whisker" (Fig 2) and adjusted to detect radio waves. This is one of the first U.S. patents of a crystal diode detector.

THE FIRST CRYSTAL DETECTORS



(A)



(B)

(C)

(D)

Shown above are photos of various commercial and hobbyist crystal diode detectors from the 1920s through the 1950s. As discussed earlier, during this timeframe, most commercial radio manufacturers were using vacuum tube detectors, due to the "hand-adjusted" and sometimes erratic behavior of the "cats whisker" crystal technology. Note also the use of different semiconductor elements, such as galena, carborundum, silicon and the mysterious "Atomic" crystal. Manufacturing dates for the above devices are (A) 1950s, (B) (C) and (D) 1920s/1930s, and finally, the first commercial crystal diode (1N34) shown at the bottom of photo (D) is from the mid 1940s – be sure to include historic devices such as these in your research and collection.

WHAT'S INCLUDED WITH YOUR HISTORIC GERMANIUM CRYSTAL DIODES

ONE EACH OF THESE CLASSIC 1950S GERMANIUM RADIO DIODES: KEMTRON 1N34 SYLVANIA 1N34A CBS/HYTRON 1N81
EACH DIODE IS STORED IN A UNIQUE TRANSISTOR MUSEUM DISPLAY ENVELOPE
THIS BOOKLET CONTAINS TRANSISTOR MUSEUM PHOTOGALLERY DOCUMENTATION WITH DETAILED PHOTOGRAPHS AND HISTORICAL RESEARCH ABOUT YOUR DIODES
ALL PRINTED MATERIAL IS CONTAINED IN ARCHIVAL QUALITY SHEET PROTECTORS AND ENCLOSED IN AN EXPANDABLE BINDER
YOU'LL ALSO RECEIVE ADDITIONAL TRANSISTOR MUSEUM DISPLAY ENVELOPES AND STORAGE SHEETS TO ASSIST IN EXPANDING YOUR OWN HISTORIC DIODE RESEARCH AND DEVICE COLLECTION

SUGGESTED NEXT STEPS FOR THE HISTORIAN, ENGINEER, EXPERIMENTER, RESEARCHER AND HOBBYIST

Research a Specific Company or Type of Diode: After you've started a basic collection of early diode types, an excellent next step would be to expand your collection with emphasis on a particular historic company of interest or a specific type or number range of devices. For example, the earliest commercial diodes were labeled with a 1NXX numbering system, such as 1N34, and a suggested research strategy might be to identify and collect the complete range of devices from 1N21 to 1N100. Another approach might be to collect the complete range of known "1N" types from a pioneering diode company, such as Sylvania, Kemtron, or CBS/Hytron.

Expand Your Historic Diode Collection: Adding to the historic germanium diodes included in this Volume 1, an excellent next step would be to research, locate and acquire examples of the many types of historic devices developed in the 1940s, 1950s, 1960s and 1970s. Building your own personal collection of a well-researched variety of devices important to the history of diode technology could provide immense educational value for years to come. Use the included Transistor Museum display envelopes to get started!

Build a Modern Replica of an Early Kit or Historic Construction Article Project: With the wealth of historic documentation now available (for example, review a copy of Popular Electronics magazine from the 1950s), it is possible to build a modern version of a historic kit or vintage construction article project. We have provided two historic crystal diode radio examples in this booklet (see pages 9 and 10), and you can find many more vintage project articles in readily available books and magazines.

Check Back Often at: TRANSISTORMUSEUM.COM
The Museum continues to expand and you'll find detailed research, photos, Oral Histories, and material to assist you in this exciting field of semiconductor history.

LEARNING MORE ABOUT YOUR HISTORIC GERMANIUM CRYSTAL DIODES

1N34	**AMPEREX,ELECTRON RESEARCH INC, CANADIAN GENERAL ELECTRIC COMPANY LTD, GENERAL ELECTRIC CO, GENERAL INSTRUMENT CORP, ITT SEMICONDUCTORS, KEMTRON ELECTRON PRODUCTS, OHMITE MANUFACTURING, PHILIPS ELECTRON DEVICES LIMITED, SEMI-ELEMENTS, TRANSITRON ELECTRONIC CORP**
1N34A	**AMPEREX, COSEM, ELECTRON RESEARCH INC, CANADIAN GENERAL ELECTRIC COMPANY LTD, GENERAL ELECTRIC CO, GENERAL INSTRUMENT CORP, HITACHI LTD, HUGHES SEMICONDUCTOR DIVISION, HUGHES INTERNATIONAL, ITT SEMICONDUCTORS, KEMTRON ELECTRON PRODUCTS, MISTRAL, NEW JAPAN RADIO CO LTD, NUCLEONIC PRODUCTS CO, OHMITE MANUFACTURING, PHILIPS ELECTRON DEVICES LIMITED, SEMI-ELEMENTS, SYLVANIA, TRANSITRON ELECTRONIC CORP**
1N81	**COSEM, ELECTRON RESEARCH INC, CANADIAN GENERAL ELECTRIC COMPANY LTD, GENERAL ELECTRIC CO, HUGHES SEMICONDUCTOR DIVISION, ITT SEMICONDUCTORS, KEMTRON ELECTRON PRODUCTS, MISTRAL, NUCLEONIC PRODUCTS CO, OHMITE MANUFACTURING, SESC, SEMI-ELEMENTS, SYLVANIA, TRANSITRON ELECTRONIC CORP**

Since initial production in the 1940s and 1950s, the 1N34, 1N34A and 1N81 diodes continued to be manufactured for many years. This long standing production is indicative of the widespread use of these devices in commercial and military products. The above chart is a comprehensive list of manufacturers of these diodes, as documented in 1966 (see reference **[5]**). Note that the original developer of the famous 1N34 (Sylvania) was no longer making this device in 1966. Corporate success and production varied substantially through the decades of early semiconductor history, and lists such as the above would likely look very different when developed for different production dates.

LEARNING MORE ABOUT YOUR HISTORIC GERMANIUM CRYSTAL DIODES

BIBLIOGRAPHY OF EARLY CRYSTAL DIODE REFERENCE MATERIAL

This bibliography provides additional information regarding the material that has been referenced in your booklet. These publications are no longer in print, but you should be able to find them through online auctions or online vintage book sellers. All are highly recommended and provide a comprehensive view of crystal diode history and technology.

[1] Lee, Thomas H., ***The (Pre-) History of the Integrated Circuit: A Random Walk,*** IEEE Portal, Solid State Circuits Society, Spring 2007. Comments: Tom Lee's article on the semiconductor antecedents of integrated circuit technology provides a comprehensive and very readable account of the first crystal detectors, beginning with Braun's work in the 1870s and including an extensive discussion of wireless (radio) detectors of the early 1900s. Also provided is an excellent bibliography related to crystal diode history. Highly recommended reading! You can access this article on the web as follows: Go to IEEE.org and use the search string - "Tom Lee IC History".

[2] Kilpatrick, David G. and Dittrich, William A., ***Diode Reference Book***. Philadelphia: M. W. Lads Publishing Co. 1965. Comments: This is a little known diode reference text, and is a "must-have" for those interested in mid-century diode technology. You'll find a comprehensive listing of all available diode types, and much additional information such as a listing of manufacturers, basic diode circuits and a brief history of diodes.

[3] Conti, Theodore., ***Metallic Rectifiers and Crystal Diodes.*** New York: John F. Rider Publisher, Inc. 1958. Comments: This is a useful and informative volume covering crystal diode history, technical descriptions, photos and detailed specifications – all documented from a mid 1960s perspective.

[4] ***The Radio Amateur's Handbook.*** Published by the American Radio Relay League. , West Hartford, CT. Comments: Beginning publication in the 1920s, this Handbook has been the "master reference" for amateur radio operators. Each annual edition documents ongoing progress in the field of electronics. The 1956 edition provides a comprehensive list of available crystal diode types from that time period.

LEARNING MORE ABOUT YOUR HISTORIC GERMANIUM CRYSTAL DIODES

BIBLIOGRAPHY OF EARLY CRYSTAL DIODE REFERENCE MATERIAL (Continued)

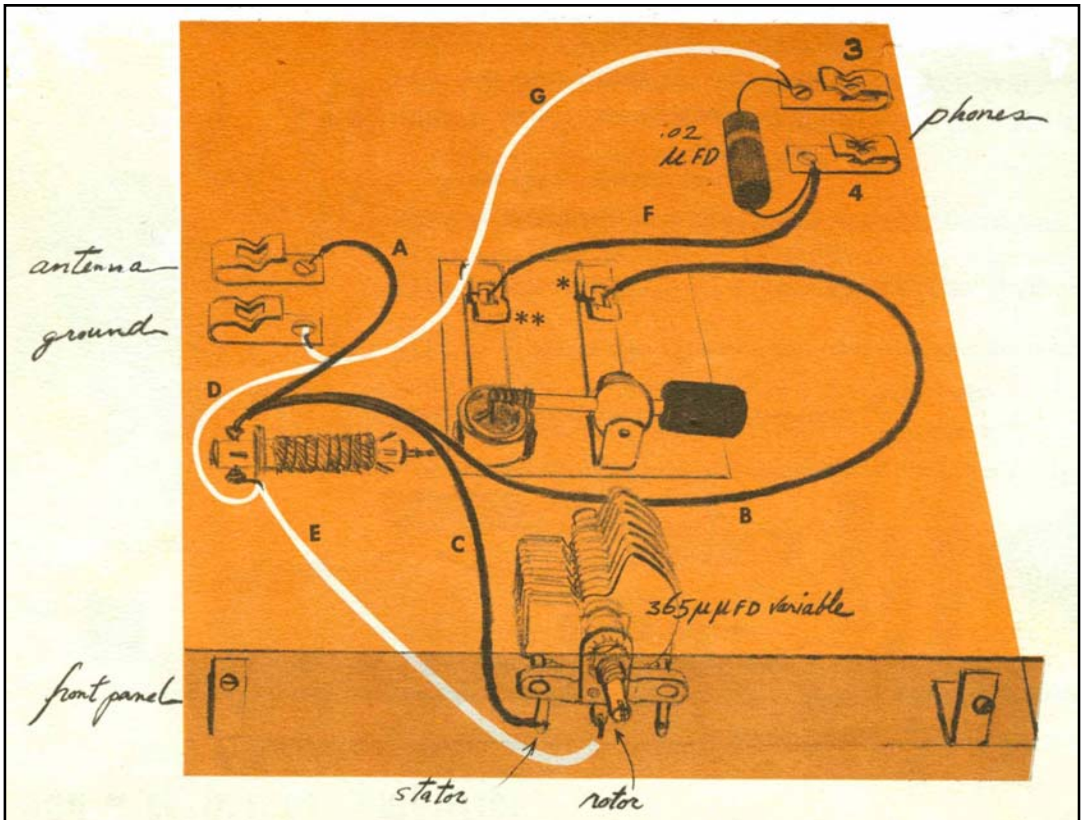
[5] ***Semiconductor Diode and Silicon Controlled Rectifier Characteristics Tabulation.*** **D.A.T.A.** series published by Derivation and Tabulation Associates, Inc. Orange NJ. Comments: To quote from the 17th edition, 1966 "This tabulation is designed to report comprehensively on what is presently being produced (throughout the free world) in this specific component field". Annual editions of the D.A.T.A. series were likely the most comprehensive listing of component specifications published in the 1950s, 1960s and 1970s. The diode series provided extensive technical information, including type numbers, performance parameters, outline drawings and manufacturer's information. The 13th edition (April 1964) was more than 500 pages.

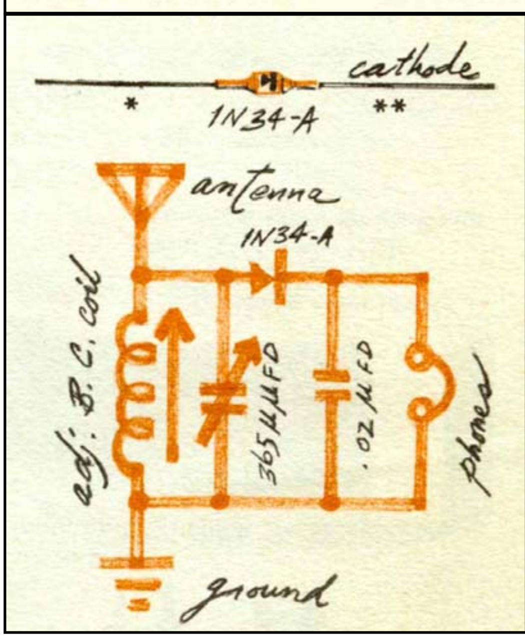
[6] ***Transistor Substitution Handbook.*** Howard W. Sams and Co. Fourth Edition, January 1963. Comments: Although primarily intended to provide a list of transistor substitution types, included is a comprehensive list of crystal diode substitutions. This is very useful information for documenting early crystal diode history.

[7] Smith, Joseph A., ***Fun Time Radio Building.*** Children's Press, 1961. Comments: If you were a young hobbyist and wanted to build a radio circuit in the 1960s, you may have used this book. Designed to assist young engineers in constructing simple circuits, there is frequent use of crystal diode technology. In addition, there is basic use of vacuum tubes and transistors.

[8] ***Crystal diode Company-specific literature***. Comments: Most crystal diode manufacturers from the 1950s and 1960s published a variety of literature regarding the specifications and use of their crystal diodes. Particularly active in the early days were Sylvania and CBS, with multiple publications from each company. An example is: ***Electronic Shortcuts for Hobbyists,*** published by Sylvania Electronics Products Inc, – various editions dated from the 1940s and 1950s. This volume contains 24 crystal diode circuit applications, as well as Sylvania crystal diode specifications. Company-specific literature such as this volume can be very useful when documenting early crystal diode history.

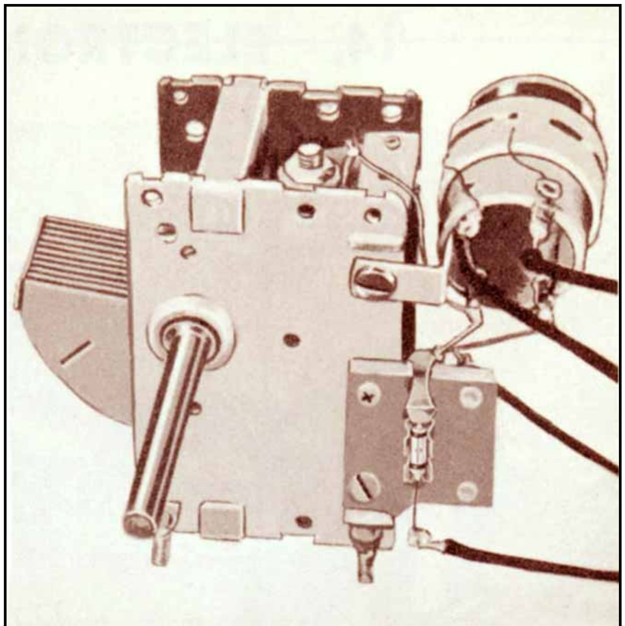
LEARNING MORE ABOUT YOUR HISTORIC GERMANIUM CRYSTAL DIODES

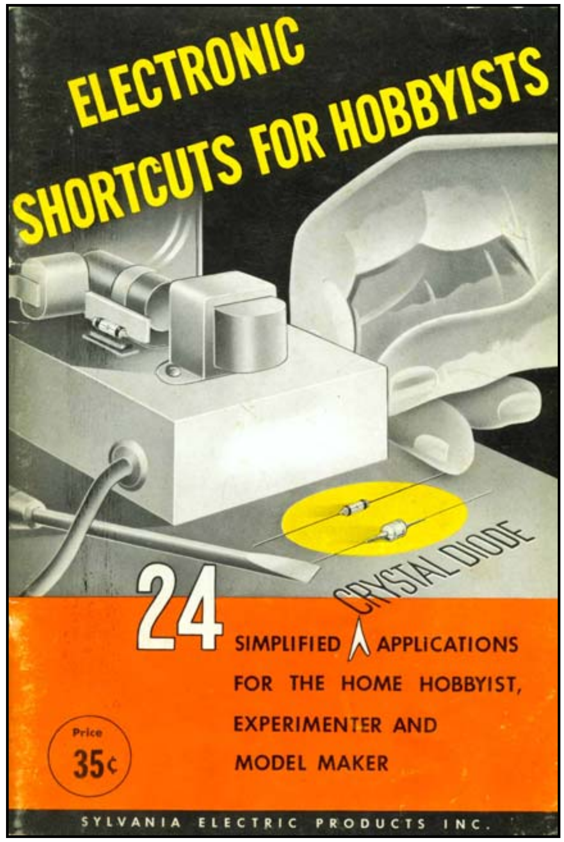




Shown on this page are details of a historic crystal diode receiver, excerpted from reference [7]. Of interest in this project is the use of either a "cats whisker" detector (shown above), or the suggested improvement of using a 1N34A crystal diode detector (shown at left). The author of this 1961 text has provided detailed construction steps, along with schematics and colorful illustrations. Use these project details to build a vintage crystal diode receiver - all three of the crystal diodes included with your Volume 1 should work just fine when used with this radio.

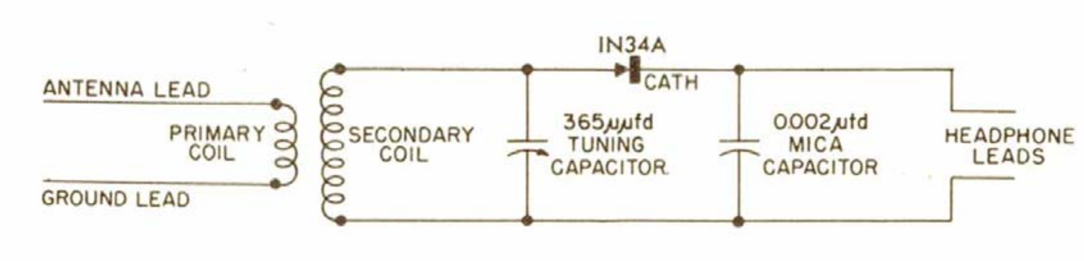
LEARNING MORE ABOUT YOUR HISTORIC GERMANIUM CRYSTAL DIODES





As noted in reference [8], many of the early crystal diode manufacturers, such as Sylvania, CBS, and Raytheon published a variety of literature regarding the specifications and use of their crystal diodes. Particularly active was Sylvania, which began publication of this type of material in the mid 1940s. Shown on this page are sections of a crystal diode radio project from the early 1950s booklet, "Electronic Shortcuts for Hobbyists". An illustration of the radio is shown above, with the 1N34A diode in the foreground. The schematic is shown below.

This miniature crystal set covers the entire standard broadcast band. Headphones connected to it should have a resistance rating of at least 2000 ohms. Do not use crystal type headphones. When loudspeaker operation is desired, the output leads may be connected directly to an audio amplifier with a 500,000-ohm ½-watt carbon resistor connected between the latter's input terminals.



BUILDING YOUR OWN COLLECTION OF HISTORIC GERMANIUM CRYSTAL DIODES

Shown below is an example of one approach to building your own collection of historic germanium diodes. This list is based on a 1950s CBS-Hytron company publication, "Crystal Diode Manual, Third Edition". Using this list (continued on the next page), you can build your collection one historic company at time!

CBS TYPE	USE	NOTES	IN MY COLLECTION?
1N34	General Purpose	First germanium crystal diode type	Yes - Kemtron
1N34A	General Purpose	Early glass cased version of 1N34	Yes - Sylvania
1N35	Matched Pair 1N34A	Rare dual-diode assembly	
1N38/38A	High Reverse Voltage	Glass/plastic case	
1N39/39A	High Reverse Voltage	Plastic case	
1N40	Quad (4 1N34's)	Mounted in a vacuum tube base	
1N48	General Purpose Detector	CBS schematic as FM discriminator	
1N51	General Purpose	CBS schematic as AM detector	
1N52	General Purpose	Glass/plastic case.	
1N54	General Purpose	CBS schematic as AVC circuit	
1N54A	General Purpose	Glass/plastic case	
1N55 1N55A	General Purpose High Reverse Voltage	Glass/plastic case	
1N55B	General Purpose High Reverse Voltage	Plastic case	
1N56/56A	High Conduction	Glass/plastic case	
1N58/58A	High Reverse Voltage	Glass/plastic case	

BUILDING YOUR OWN COLLECTION OF HISTORIC GERMANIUM CRYSTAL DIODES

(Continued)

This is the continuation from the previous page of the list of germanium diodes available from CBS-Hytron in the 1950s (this list shows all available CBS germanium diodes with a "1N" number less than 1N100). As suggested before, use this list to research and collect all the diodes documented in the historic literature.

CBS TYPE	USE	NOTES	IN MY COLLECTION?
1N60	Video Detector	Very commonly used as detector in AM radios	
1N63	General Purpose	Glass/plastic case	
1N64	Video Detector	Glass/plastic case	
1N65	General Purpose	Glass/plastic case	
1N67	General Purpose	Plastic case	
1N67A	General Purpose	Glass case	
1N69	General Purpose JAN (Army/Navy)	Plastic case	
1N70	General Purpose JAN (Army/Navy)	Plastic case	
1N71	Quad (4 1N56's)	Mounted in a vacuum tube base	
1N73	Quad (4 General Purpose)	Mounted in a vacuum tube base	
1N74	Quad (4 General Purpose)	Mounted in a vacuum tube base	
1N75	General Purpose	Glass/plastic case	
1N81	General Purpose JAN (Army/Navy)	Plastic case	Yes - CBS

BUILDING YOUR OWN COLLECTION OF HISTORIC GERMANIUM CRYSTAL DIODES

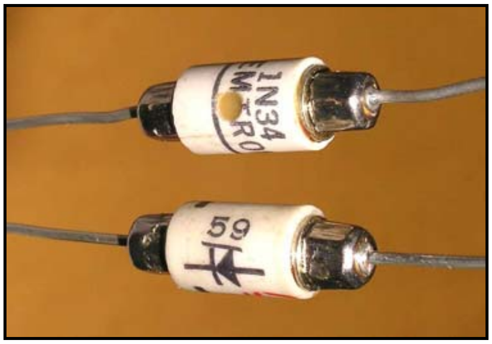
Original device packaging, as shown at left, can be a useful addition to your collection. This colorful material can frequently provide device or corporate data that is invaluable in completing your research. The material shown is from the 1950s.

Shown at right is a macro photograph of seven 1950s/60s germanium crystal diodes, chosen to represent the range of case styles, colors, types and manufacturers that could be the basis for expanding your collection. Beginning at left: National Union 1N51, Sylvania 1N58A, Radio Receptor 1N51, Raytheon CK705/1N34, International Rectifier 1N52, Transitron 1N54 and Hughes 1N61. Each of these companies and specific diode types can be further researched using the references provided with your book – a great way to document your expanding collection!

Crystal diode technology, devices and related antecedents span over a century, from the first "cat's whisker" crystal detectors developed in the early years of the 20th century to the more robust commercial crystal diodes, beginning with the Sylvania 1N34 developed in the mid 1940s. As shown in the photos above, these unique semiconductors have been marketed by a variety of different companies, packaged in colorful and graphically appealing containers, and manufactured in a broad range of plastic, glass and ceramic cases. The devices, packaging and specifications for crystal diodes documented in this book are just a starting point for those interested in researching this fascinating technology. The Photo Gallery descriptions of your diodes (beginning on the next page), and the display envelopes included at the rear of the book, have been provided as a first step for documenting and expanding your collection of these marvelous and historic devices.

CHECK BACK OFTEN AT TRANSISTORMUSEUM.COM
YOU'LL FIND ADDITIONAL HISTORICAL SEMICONDUCTOR MATERIAL FOR YOUR RESEARCH

TRANSISTOR MUSEUM™
Historic Transistor Photo Gallery



Diode Size (3/16" Diameter X 3/8" L)
Date Code "59" - Most Units Have No Date


KEMTRON
GERMANIUM CRYSTAL DIODE
TYPE 1N 34
Made in U. S. A.
KEMTRON ELECTRON PRODUCTS INC.
23 BROWN STREET SALEM, MASSACHUSETTS

3 1/2" X 2 1/4" Foldover Paper Packaging
See Page 2 for More Kemtron Diode Photos

KEMTRON 1N34 GERMANIUM CRYSTAL DIODE

TYPE
Germanium Point Contact Diode

USAGE
General Purpose

DATE INTRODUCED
1950s

CASE STYLES
White Ceramic

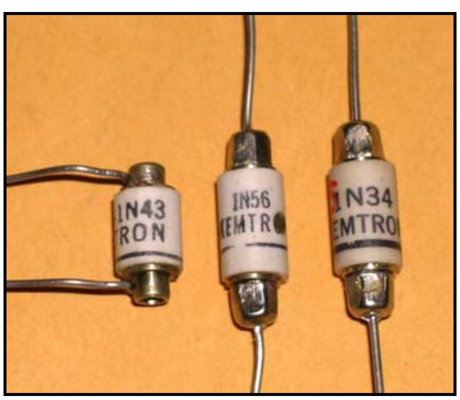
AVAILABILITY
Rare (Production Limited to 1950s/1960s)

HISTORIC NOTES
The 1N34 germanium crystal diode had been originally introduced by Sylvania in 1946, and soon became a large commercial success. Into the 1950s and 1960s, many electronics manufacturers began to offer their own versions of this device. KEMTRON was one of those companies to "second-source" the 1N34. Shown above at top left are examples of the KEMTRON 1N34; note the white ceramic case, which is similar in style to the original case style used by Sylvania in the 1940s. The paper packaging for the device is also shown, and lists the address for KEMTRON as Salem, Massachusetts. Little is known about KEMTRON, which did not advertise extensively in electronic publications and apparently did not offer much in the way of product documentation. It is possible that KEMTRON was formed by ex-Sylvania employees, who were familiar with diode technology. (Note that an early Sylvania semiconductor facility was located close by in Woburn, Massachusetts). KEMTRON manufactured a variety of germanium and silicon diodes into the 1960s – the manufacturing facility was sold to the city of Newburyport in 1980 and demolished in 1981. KEMTRON diodes are truly unique and represent a classic technology, manufactured by a little known and historic company.

TRANSISTOR MUSEUM™

Historic Transistor Photo Gallery

Shown above are three examples of KEMTRON diode packaging. Topmost is a military package, dated 1963, for 1N34. The cardboard box is dated 1953 and contains a 1N43 diode. The bottom paper packaging was used in the latter 1950s for diodes such as the 1N34 and 1N56. Of interest is the enlargement shown above which apparently documents the corporate move of KEMTRON from Salem to Newburyport Massachusetts.



KEMTRON 1N34 GERMANIUM CRYSTAL DIODE

Page 2

AVAILABILITY OF TRANSISTORS

COMPANY	MONTHLY PRODUCTION CONTACT	MONTHLY PRODUCTION JUNCTION	DELIVERY TIME CONTACT	DELIVERY TIME JUNCTION	REMARKS
Federated Semi-Con-ductor Co., New York, N. Y.	...	...	...	...	Sample lots available in May, 1952
General Electric Syracuse, N. Y.	800	...	6-8 wks.	Not quoting	Sample lots Junction type Oct.-Nov. 1952
Kemtron Salem, Mass.	...	...	...	...	Sample lots Point contact Sept. 1952
RCA Harrison, N. J.	400	...	4-6 wks.	...	Sample lots Junction type Oct.-Dec. 1952
Radio Receptor New York, N. Y.	200	...	4-8 wks.	...	
Raytheon Newton, Mass.	1,000	...	4 wks.	Not quoting	Sample lots Junction type Nov.-Dec. 1952
Sylvania Boston, Mass.	...	...	...	...	Sample lots Point contact Aug. 1952
Western Electric New York, N. Y.	6,000	Less than 100	4-8 wks.	Not quoting	

KEMTRON Transistors?

The above chart was shown in the July 1952 issue of the Radio Electronics magazine and was intended to provide a summary of transistor production at this early time in transistor history. Note the mention of KEMTRON in the third row, with the claim that sample lots of point contact transistors would be available in Sept 1952. It would have been technically possible for KEMTRON engineers to fabricate point contact transistors, since the technology and required materials were similar to the manufacture of germanium point contact diodes, such as the 1N34. However, there is no known documentation of KEMTROM transistors, so the effort may have terminated prior to commercialization. Shown are left are three examples of KEMTRON germanium diodes (1N43, 1N56 and 1N34).

TRANSISTOR MUSEUM™
Historic Transistor Photo Gallery

Diode Size (1/8" Diameter X 1/4" L)
No Date Code

4" X 1 1/4" Foldover Cardboard Packaging

See Page 2 for More SYL 1N34A Diode Photos

SYLVANIA 1N34A GERMANIUM CRYSTAL DIODE

TYPE
Germanium Point Contact Diode

USAGE
General Purpose/Hobbyist

DATE INTRODUCED
Late 1940s

CASE STYLES
Glass Large (1940s-1950s)

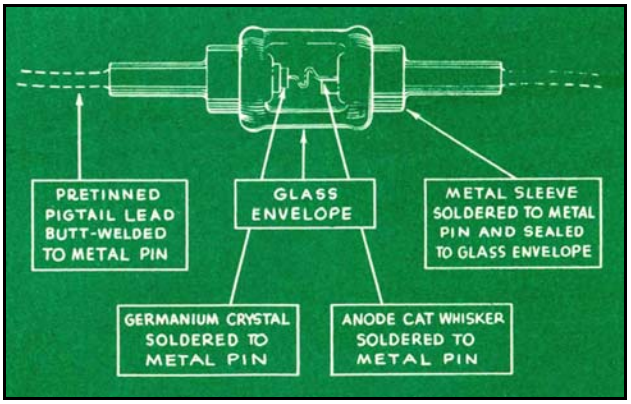
AVAILABILITY
Common (Large Scale Commercial Use)

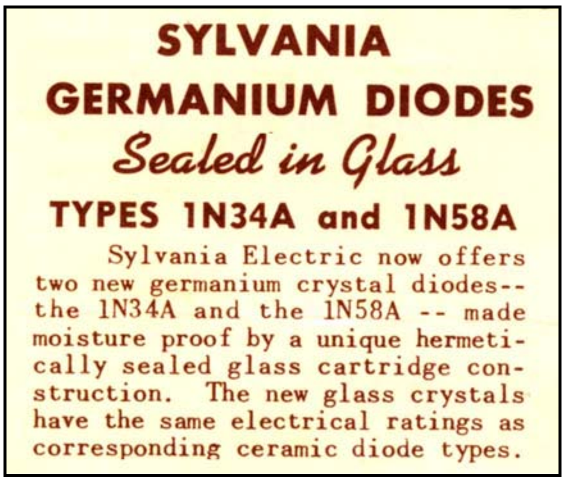
HISTORIC NOTES

Sylvania introduced the first commercial germanium crystal diode in 1946, with the famous 1N34. This was a general purpose diode that found widespread use in numerous commercial and hobbyist applications. Sylvania expanded this successful line of devices with additional types, such as the 1N38, 1N39, 1N40 thru 1N42, and 1N54 thru 1N58. These first Sylvania diodes used large white ceramic cases. By 1949, Sylvania began to offer smaller, lighter weight versions of these diodes with hermetically sealed glass cases – these newer devices were designated with the letter "A" following the original device number, so that the 1N34A was the glass-cased version of the original ceramic-cased 1N34. The glass diodes were a commercial success, and Sylvania continued to produce even smaller devices throughout the 1950s. The 1N34A is a rugged, high performing germanium diode, electrically equivalent to the original 1946 1N34 diode, and useful in a wide variety of historic and modern applications. Although manufactured over 50 years ago, most 1N34A Sylvania diodes are still functional, and will provide quite excellent results when used in circuit applications of the time, such as the classic crystal diode AM radio receiver built by thousands of engineers and hobbyists since the 1950s.

SYLVANIA 1N34A GERMANIUM CRYSTAL DIODE

Page 2





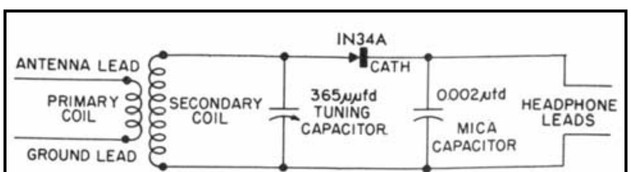
SYLVANIA

GERMANIUM DIODES

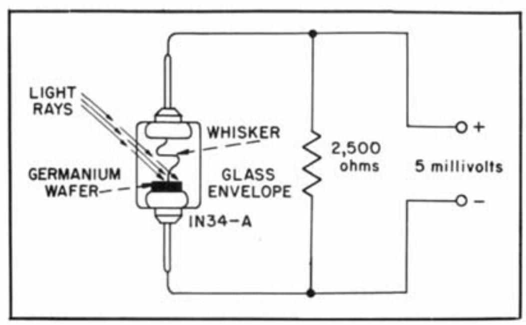
Sealed in Glass

TYPES 1N34A and 1N58A

Sylvania Electric now offers two new germanium crystal diodes-- the 1N34A and the 1N58A -- made moisture proof by a unique hermetically sealed glass cartridge construction. The new glass crystals have the same electrical ratings as corresponding ceramic diode types.



Circuit of the Crystal Radio.



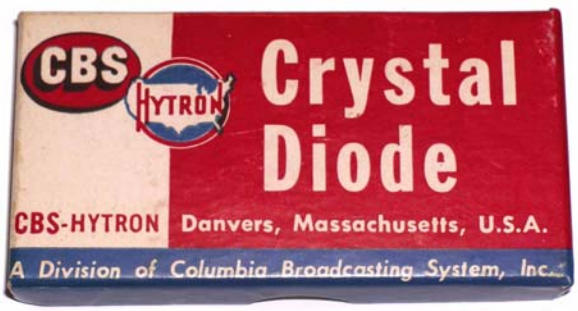
Germanium Diode as Self-Generating Photocell.

Sylvania 1N34A

The two scans shown at upper left are from a 1949 Sylvania specification sheet for the newly released 1N34A germanium diode. Note the detailed drawing showing construction of the glass case and internal components. Additional text stresses the advantages of the smaller, lighter-weight devices, while still maintaining equivalent electrical performance to the original ceramic-cased 1N34. The photo at top right shows the differences between the original 1N34 case style (shown with green lettering as was used by Sylvania in the 1940s) compared with the more modern glass-cased 1N34A. The two schematics shown above are copied from the 1951 Sylvania publication, "Electronic Shortcuts for Hobbyists", which documented 24 crystal diode circuit applications. The radio schematic is a real classic, easy to build and capable of excellent AM reception. The photocell circuit illustrates a unique advantage of a glass case (allows light to activate the germanium), when compared to the opaque ceramic-cased 1N34.

TRANSISTOR MUSEUM™
Historic Transistor Photo Gallery

Diode Size (1/4" Diameter X 3/8" L)
Date Code on Similar Units (1959)



3" X 1 1/2" X 3/8" Cardboard Box with Removable Lid

See Page 2 for More 1N81 Diode Photos

CBS HYTRON 1N81 GERMANIUM CRYSTAL DIODE

TYPE
Germanium Point Contact Diode

USAGE
General Purpose/Military

DATE INTRODUCED
Early 1950s

CASE STYLES
Brown phenolic plastic

AVAILABILITY
Rare (Production Limited to 1950s)

HISTORIC NOTES

By the late 1940s, the germanium crystal diode market was expanding into the hundreds of thousands of units annually, largely to support the growth of the TV receiver market. Several large vacuum manufacturers became leaders in diode production, including Sylvania, General Electric and Raytheon. Other smaller electronics companies entered this market, including CBS Hytron, a company formed when CBS purchased a small vacuum tube company (Hytron) in order to establish a presence in the semiconductor manufacturing field. CBS was offering a complete range of germanium diodes (and transistors), beginning early in the 1950s. Most of these products were based on device types and technologies created by larger, more research oriented companies. For example, CBS was one of many companies to offer a "1N34" germanium diode, based on the universally popular device developed by Sylvania in the mid 1940s. The 1N81 diode had been developed initially by General Electric in 1950, primarily to support the military need for a rugged, general purpose germanium diode. CBS was one of several companies to provide second-sourcing for the 1N81, and introduced their version in 1952. These are excellent general purpose diodes, rugged and reliable, and can be used in most circuits interchangeably with the 1N34.

CBS HYTRON 1N81 GERMANIUM CRYSTAL DIODE
Page 2

At left are photos of additional CBS semiconductor packaging styles from the 1950s. The top package is a "matchbook" foldover style from 1954, and contains a brown phenolic plastic 1N64. The center package has a snapped opening tab, and contains a small glass 1N64. The lower package is a "matchbook" foldover style, and contains a small glass 1N99. Most CBS 1950s semiconductors are easily recognizable from the unique and colorful packaging used by this notable company.

CBS DIODES

	PIV	Min. Fwd. MA@1V	Max. INV ua	Uses	Net 1-99	Net 100, UP
IN34A	75	5	50	G P	.45	.30
IN35	75	7.5	10	M P	1.80	1.20
IN38/A/B	120	4-25	6	High Rev V	.90	.60
IN39A(P)	225	5	65	High Rev V	3.75	2.50
IN48	85	4	833	G P Det	.33	.22
IN51	50	2.5	1660	G P	.33	.22
IN52	85	4.0	150	G P	.90	.60
IN54/A	75	5	7	G P	.90	.60
IN55/A	170	4	300	High Rev V	1.87	1.25
IN56/A	59	15	300	High Cond	.98	.66
IN58/A	120	5	600	High Rev V	.90	.60
IN60	30	3	67	Vid Det	.50	.33
IN63	125	4	50	G P	1.27	.85
IN64	20	—	200	Vid Det	.50	.33
IN65	85	2.5	200	G P	.53	.35
IN67/A(G)	100	4	5	High Rev R	1.07	.71
IN68/A(G)	130	3	625	High Rev V	1.20	.80
IN69/A(P)	75	5-25	30	G P	.48	.32
IN70/A(P)	125	3-25	25	G P	.71	.47
IN75(G)	125	2.5	50	G P	.90	.60
IN81/A(P)	50	3.25	10	G P	.87	.57

Suffix P—Plastic Case; G—Glass Case; GP—General Purpose; MP—Matched Pair; Rev—Reverse; V—Volts; Det—Detector; Cond—Conduction; Vid—Video; R—Resistance;

This is a section of the "CBS Transistors and Diodes" page of the 1960 2nd edition of the Lafayette Radio Semiconductor Directory. Although offering a wide range of germanium products (including the 1N81) in this catalog, CBS soon exited the semiconductor business.

EVOLUTION OF CASE STYLES

Shown above are three examples of the evolving case styles of 1N81 throughout the 1950s. At left is an early 1950s GE device, which is somewhat crudely made and not hermetically sealed. The CBS device (from the mid 1950s) has a very robust phenolic plastic case, suitable for military use. At right is a modern 1960s hermetically sealed glass device from Transitron.

BUILDING YOUR OWN COLLECTION OF HISTORIC GERMANIUM CRYSTAL DIODES

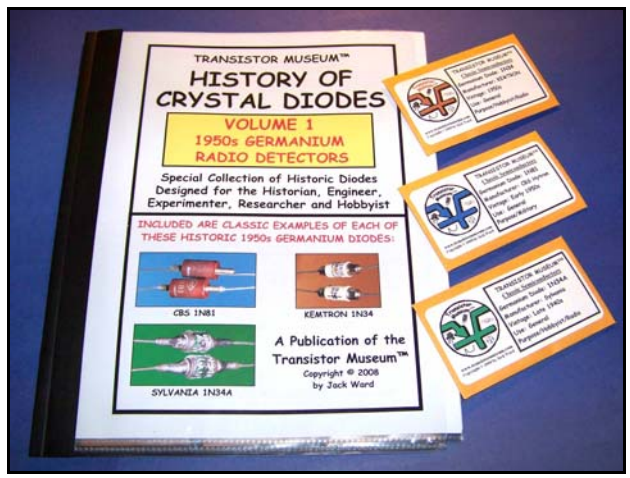
If you've enjoyed this web-based pdf version of this History of Crystal Diodes Publication, visit the Transistor Museum Store to purchase a hardcopy version, which also includes packaged examples of all three historic diodes as shown below, as well as additional storage/display envelopes for own collection.

http://www.semiconductormuseum.com/MuseumStore/MuseumStore_Index.htm

HISTORY OF CRYSTAL DIODES VOLUME 1

Shown at left is a photo of the booklet, opened to the rear section, which contains the storage sheets for the three diodes in display envelopes and the six additional display envelopes provided to assist you in building your own historic diode collection.

Shown above is a photo of the two types of display envelopes you'll receive. The lower envelope contains one of the three historic diodes (the 1N81 is shown) and the upper envelope is one of six empty display envelopes provided for your own use with future research material. All nine display envelopes can be stored securely in the rear section of the binder.



Your historic diodes, photos, descriptive text and storage envelopes are contained in the expandable three-ring report binder as shown above. The display envelopes are securely stored in plastic sheet holders at the rear section of the booklet. Archival quality sheet protectors are used for storage of all pages. For size comparison, three display envelopes for your historic diodes are shown above, next to the completed Volume 1 binder.

4

Antennas & Transmission Lines

The transmitter that generates the RF[1] power to drive the antenna is usually located at some distance from the antenna terminals. The connecting link between the two is the ***RF transmission line***. Its purpose is to carry RF power from one place to another, and to do this as efficiently as possible. From the receiver side, the antenna is responsible for picking up any radio signals in the air and passing them to the receiver with the minimum amount of distortion, so that the radio has its best chance to decode the signal. For these reasons, the RF cable has a very important role in radio systems: it must maintain the integrity of the signals in both directions.

There are two main categories of transmission lines: cables and waveguides. Both types work well for efficiently carrying RF power at 2.4 GHz.

Cables

RF cables are, for frequencies higher than HF, almost exclusively coaxial cables (or ***coax*** for short, derived from the words "of common axis"). Coax cables have a core ***conductor*** wire surrounded by a non-conductive material called ***dielectric,*** or simply ***insulation***. The dielectric is then surrounded by an encompassing shielding which is often made of braided wires. The dielectric prevents an electrical connection between the core and the shielding. Finally, the coax is protected by an outer casing which is generally made

1. Radio Frequency. See chapter two for discussion of electromagnetic waves.

from a PVC material. The inner conductor carries the RF signal, and the outer shield prevents the RF signal from radiating to the atmosphere, and also prevents outside signals from interfering with the signal carried by the core. Another interesting fact is that high frequency electrical signal always travels along the outer layer of a conductor: the larger the central conductor, the better signal will flow. This is called the “skin effect”.

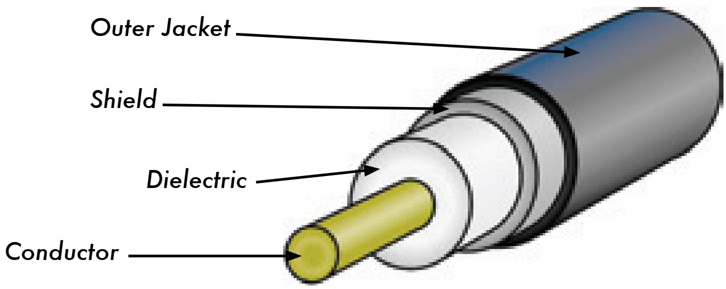


Figure 4.1: Coaxial cable with jacket, shield, dielectric, and core conductor.

Even though the coaxial construction is good at containing the signal on the core wire, there is some resistance to the electrical flow: as the signal travels down the core, it will fade away. This fading is known as ***attenuation***, and for transmission lines it is measured in decibels per meter (***dB/m***). The rate of attenuation is a function of the signal frequency and the physical construction of the cable itself. As the signal frequency increases, so does its attenuation. Obviously, we need to minimize the cable attenuation as much as possible by keeping the cable very short and using high quality cables.

Here are some points to consider when choosing a cable for use with microwave devices:

1. “The shorter the better!” The first rule when you install a piece of cable is to try to keep it as short as possible. The power loss is not linear, so doubling the cable length means that you are going to lose much more than twice the power. In the same way, reducing the cable length by half gives you more than twice the power at the antenna. The best solution is to place the transmitter as close as possible to the antenna, even when this means placing it on a tower.

2. “The cheaper the worse!” The second golden rule is that any money you invest in buying a **good quality** cable is a bargain. Cheap cables are intended to be used at low frequencies, such as VHF. Microwaves require the highest quality cables available. All other options are nothing but a dummy load[2].

---

2. A dummy load is a device that dissipates RF energy without radiating it. Think of it as a heat sink that works at radio frequencies.

3. Always avoid RG-58. It is intended for thin Ethernet networking, CB or VHF radio, not for microwave.

4. Always avoid RG-213. It is intended for CB and HF radio. In this case the cable diameter does not imply a high quality, or low attenuation.

5. Whenever possible, use ***Heliax*** (also called "Foam") cables for connecting the transmitter to the antenna. When Heliax is unavailable, use the best rated LMR cable you can find. Heliax cables have a solid or tubular center conductor with a corrugated solid outer conductor to enable them to flex. Heliax can be built in two ways, using either air or foam as a dielectric. Air dielectric Heliax is the most expensive and guarantees the minimum loss, but it is very difficult to handle. Foam dielectric Heliax is slightly more lossy, but is less expensive and easier to install. A special procedure is required when soldering connectors in order to keep the foam dielectric dry and uncorrupted. LMR is a brand of coax cable available in various diameters that works well at microwave frequencies. LMR-400 and LMR-600 are a commonly used alternative to Heliax.

6. Whenever possible, use cables that are pre-crimped and tested in a proper lab. Installing connectors to cable is a tricky business, and is difficult to do properly even with the proper tools. Unless you have access to equipment that can verify a cable you make yourself (such as a spectrum analyzer and signal generator, or time domain reflectometer), troubleshooting a network that uses homemade cable can be difficult.

7. Don't abuse your transmission line. Never step over a cable, bend it too much, or try to unplug a connector by pulling directly the cable. All of those behaviors may change the mechanical characteristic of the cable and therefore its impedance, short the inner conductor to the shield, or even break the line. Those problems are difficult to track and recognize and can lead to unpredictable behavior on the radio link.

Waveguides

Above 2 GHz, the wavelength is short enough to allow practical, efficient energy transfer by different means. A waveguide is a conducting tube through which energy is transmitted in the form of electromagnetic waves. The tube acts as a boundary that confines the waves in the enclosed space. The Faraday cage effect prevents electromagnetic effects from being evident outside the guide. The electromagnetic fields are propagated through the waveguide by means of reflections against its inner walls, which are considered perfect conductors. The intensity of the fields is greatest at the center along the X dimension, and must diminish to zero at the end walls because the existence of any field parallel to the walls at the surface would cause an infinite current to flow in a perfect conductor. Waveguides, of course, cannot carry RF in this fashion.

The X, Y and Z dimensions of a rectangular waveguide can be seen in the following figure:

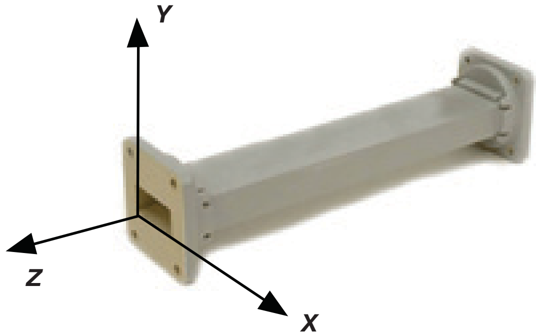


Figure 4.2: The X, Y, and Z dimensions of a rectangular waveguide.

There are an infinite number of ways in which the electric and magnetic fields can arrange themselves in a waveguide for frequencies above the low cutoff frequency. Each of these field configurations is called a ***mode***. The modes may be separated into two general groups. One group, designated ***TM*** (Transverse Magnetic), has the magnetic field entirely transverse to the direction of propagation, but has a component of the electric field in the direction of propagation. The other type, designated ***TE*** (Transverse Electric) has the electric field entirely transverse, but has a component of magnetic field in the direction of propagation.

The mode of propagation is identified by the group letters followed by two subscript numerals. For example, TE 10, TM 11, etc. The number of possible modes increases with the frequency for a given size of guide, and there is only one possible mode, called the ***dominant mode***, for the lowest frequency that can be transmitted. In a rectangular guide, the critical dimension is X. This dimension must be more than 0.5 λ at the lowest frequency to be transmitted. In practice, the Y dimension usually is made about equal to 0.5 X to avoid the possibility of operation in other than the dominant mode. Cross-sectional shapes other than the rectangle can be used, the most important being the circular pipe. Much the same considerations apply as in the rectangular case. Wavelength dimensions for rectangular and circular guides are given in the following table, where X is the width of a rectangular guide and r is the radius of a circular guide. All figures apply to the dominant mode.

Type of guide	Rectangular	Circular
Cutoff wavelength	**2X**	**3.41r**
Longest wavelength transmitted with little attenuation	**1.6X**	**3.2r**
Shortest wavelength before next mode becomes possible	**1.1X**	**2.8r**

Energy may be introduced into or extracted from a waveguide by means of either an electric or magnetic field. The energy transfer typically happens through a coaxial line. Two possible methods for coupling to a coaxial line are using the inner conductor of the coaxial line, or through a loop. A probe which is simply a short extension of the inner conductor of the coaxial line can be oriented so that it is parallel to the electric lines of force. A loop can be arranged so that it encloses some of the magnetic lines of force. The point at which maximum coupling is obtained depends upon the mode of propagation in the guide or cavity. Coupling is maximum when the coupling device is in the most intense field.

If a waveguide is left open at one end, it will radiate energy (that is, it can be used as an antenna rather than as a transmission line). This radiation can be enhanced by flaring the waveguide to form a pyramidal horn antenna. We will see an example of a practical waveguide antenna for WiFi later in this chapter.

Cable Type	Core	Dielectric	Shield	Jacket
RG-58	0.9 mm	2.95 mm	3.8 mm	4.95 mm
RG-213	2.26 mm	7.24 mm	8.64 mm	10.29 mm
LMR-400	2.74 mm	7.24 mm	8.13 mm	10.29 mm
3/8" LDF	3.1 mm	8.12 mm	9.7 mm	11 mm

Here is a table contrasting the sizes of various common transmission lines. Choose the best cable you can afford with the lowest possible attenuation at the frequency you intend to use for your wireless link.

Connectors and adapters

Connectors allow a cable to be connected to another cable or to a component of the RF chain. There are a wide variety of fittings and connectors designed to go with various sizes and types of coaxial lines. We will describe some of the most popular ones.

BNC connectors were developed in the late 40s. BNC stands for Bayonet Neill Concelman, named after the men who invented it: Paul Neill and Carl Concelman. The BNC product line is a miniature quick connect / disconnect connector. It features two bayonet lugs on the female connector, and mating is achieved with only a quarter turn of the coupling nut. BNC's are ideally suited for cable termination for miniature to subminiature coaxial cable (RG-58 to RG-179, RG-316, etc.) They have acceptable performance up to few GHz. They are most commonly found on test equipment and 10base2 coaxial Ethernet cables.

TNC connectors were also invented by Neill and Concelman, and are a threaded variation of the BNC. Due to the better interconnect provided by the threaded connector, TNC connectors work well through about 12 GHz. TNC stands for Threaded Neill Concelman.

Type N (again for Neill, although sometimes attributed to "Navy") connectors were originally developed during the Second World War. They are usable up to 18 Ghz, and very commonly used for microwave applications. They are available for almost all types of cable. Both the plug / cable and plug / socket joints are waterproof, providing an effective cable clamp.

SMA is an acronym for SubMiniature version A, and was developed in the 60s. SMA connectors are precision, subminiature units that provide excellent electrical performance up to 18 GHz. These high-performance connectors are compact in size and mechanically have outstanding durability.

The ***SMB*** name derives from SubMiniature B, and it is the second subminiature design. The SMB is a smaller version of the SMA with snap-on coupling. It provides broadband capability through 4 GHz with a snap-on connector design.

MCX connectors were introduced in the 80s. While the MCX uses identical inner contact and insulator dimensions as the SMB, the outer diameter of the plug is 30% smaller than the SMB. This series provides designers with options where weight and physical space are limited. MCX provides broadband capability though 6 GHz with a snap-on connector design.

In addition to these standard connectors, most WiFi devices use a variety of proprietary connectors. Often, these are simply standard microwave connectors with the center conductor parts reversed, or the thread cut in the opposite direction. These parts are often integrated into a microwave system using a short jumper called a ***pigtail*** that converts the non-standard connector into something more robust and commonly available. Some of these connectors include:

RP-TNC. This is a TNC connector with the genders reversed. These are most commonly found on Linksys equipment, such as the WRT54G.

U.FL (also known as ***MHF***). The U.FL is a patented connector made by Hirose, while the MHF is a mechanically equivalent connector. This is possibly the smallest microwave connector currently in wide use. The U.FL / MHF is typically used to connect a mini-PCI radio card to an antenna or larger connector (such as an N or TNC).

The ***MMCX*** series, which is also called a MicroMate, is one of the smallest RF connector line and was developed in the 90s. MMCX is a micro-miniature connector series with a lock-snap mechanism allowing for 360 degrees rotation enabling flexibility. MMCX connectors are commonly found on PCMCIA radio cards, such as those manufactured by Senao and Cisco.

MC-Card connectors are even smaller and more fragile than MMCX. They have a split outer connector that breaks easily after just a few interconnects. These are commonly found on Lucent / Orinoco / Avaya equipment.

Adapters, which are also called coaxial adapters, are short, two-sided connectors which are used to join two cables or components which cannot be connected directly. Adapters can be used to interconnect devices or cables with different types. For example, an adapter can be used to connect an SMA connector to a BNC. Adapters may also be used to fit together connectors of the same type, but which cannot be directly joined because of their gender.

Figure 4.3: An N female barrel adapter.

For example a very useful adapter is the one which enables to join two Type N connectors, having socket (female) connectors on both sides.

Choosing the proper connector

1. "The gender question." Virtually all connectors have a well defined gender consisting of either a pin (the "male" end) or a socket (the "female" end). Usually cables have male connectors on both ends, while RF devices (i.e. transmitters and antennas) have female connectors. Devices such as directional couplers and line-through measuring devices may have both male and female connectors. Be sure that every male connector in your system mates with a female connector.

2. "Less is best!" Try to minimize the number of connectors and adapters in the RF chain. Each connector introduces some additional loss (up to a few dB for each connection, depending on the connector!)

3. "Buy, don't build!" As mentioned earlier, buy cables that are already terminated with the connectors you need whenever possible. Soldering connectors is not an easy task, and to do this job properly is almost impossible for small connectors as U.FL and MMCX. Even terminating "Foam" cables is not an easy task.

4. Don't use BNC for 2.4 GHz or higher. Use N type connectors (or SMA, SMB, TNC, etc.)

5. Microwave connectors are precision-made parts, and can be easily damaged by mistreatment. As a general rule, you should rotate the outer sleeve to tighten the connector, leaving the rest of the connector (and cable) stationary. If other parts of the connector are twisted while tightening or loosening, damage can easily occur.

6. Never step over connectors, or drop connectors on the floor when disconnecting cables (this happens more often than what you may imagine, especially when working on a mast over a roof).

7. Never use tools like pliers to tighten connectors. Always use your hands. When working outside, remember that metals expand at high temperatures and reduce their size at low temperatures: a very tightened connector in the summer can bind or even break in winter.

Antennas & radiation patterns

Antennas are a very important component of communication systems. By definition, an antenna is a device used to transform an RF signal traveling on a conductor into an electromagnetic wave in free space. Antennas demonstrate a property known as ***reciprocity***, which means that an antenna will maintain the same characteristics regardless if whether it is transmitting or receiving. Most antennas are resonant devices, which operate efficiently over a relatively narrow frequency band. An antenna must be tuned to the same frequency band of the radio system to which it is connected, otherwise

the reception and the transmission will be impaired. When a signal is fed into an antenna, the antenna will emit radiation distributed in space in a certain way. A graphical representation of the relative distribution of the radiated power in space is called a ***radiation pattern***.

Antenna term glossary

Before we talk about specific antennas, there are a few common terms that must be defined and explained:

Input Impedance

For an efficient transfer of energy, the ***impedance*** of the radio, antenna, and transmission cable connecting them must be the same. Transceivers and their transmission lines are typically designed for 50Ω impedance. If the antenna has an impedance different than 50Ω, then there is a mismatch and an impedance matching circuit is required. When any of these components are mismatched, transmission efficiency suffers.

Return loss

Return loss is another way of expressing mismatch. It is a logarithmic ratio measured in dB that compares the power reflected by the antenna to the power that is fed into the antenna from the transmission line. The relationship between SWR and return loss is the following:

$$\text{Return Loss (in dB)} = 20\log_{10} \frac{\text{SWR}}{\text{SWR-1}}$$

While some energy will always be reflected back into the system, a high return loss will yield unacceptable antenna performance.

Bandwidth

The ***bandwidth*** of an antenna refers to the range of frequencies over which the antenna can operate correctly. The antenna's bandwidth is the number of Hz for which the antenna will exhibit an SWR less than 2:1.

The bandwidth can also be described in terms of percentage of the center frequency of the band.

$$\text{Bandwidth} = 100 \times \frac{F_H - F_L}{F_C}$$

...where F_H is the highest frequency in the band, F_L is the lowest frequency in the band, and F_C is the center frequency in the band.

In this way, bandwidth is constant relative to frequency. If bandwidth was expressed in absolute units of frequency, it would be different depending upon the center frequency. Different types of antennas have different bandwidth limitations.

Directivity and Gain

Directivity is the ability of an antenna to focus energy in a particular direction when transmitting, or to receive energy from a particular direction when receiving. If a wireless link uses fixed locations for both ends, it is possible to use antenna directivity to concentrate the radiation beam in the wanted direction. In a mobile application where the transceiver is not fixed, it may be impossible to predict where the transceiver will be, and so the antenna should ideally radiate as well as possible in all directions. An omnidirectional antenna is used in these applications.

Gain is not a quantity which can be defined in terms of a physical quantity such as the Watt or the Ohm, but it is a dimensionless ratio. Gain is given in reference to a standard antenna. The two most common reference antennas are the ***isotropic antenna*** and the ***resonant half-wave dipole antenna***. The isotropic antenna radiates equally well in all directions. Real isotropic antennas do not exist, but they provide useful and simple theoretical antenna patterns with which to compare real antennas. Any real antenna will radiate more energy in some directions than in others. Since antennas cannot create energy, the total power radiated is the same as an isotropic antenna. Any additional energy radiated in the directions it favors is offset by equally less energy radiated in all other directions.

The gain of an antenna in a given direction is the amount of energy radiated in that direction compared to the energy an isotropic antenna would radiate in the same direction when driven with the same input power. Usually we are only interested in the maximum gain, which is the gain in the direction in which the antenna is radiating most of the power. An antenna gain of 3 dB compared to an isotropic antenna would be written as **3 dBi**. The resonant half-wave dipole can be a useful standard for comparing to other antennas at one frequency or over a very narrow band of frequencies. To compare the dipole to an antenna over a range of frequencies requires a number of dipoles of different lengths. An antenna gain of 3 dB compared to a dipole antenna would be written as **3 dBd**.

The method of measuring gain by comparing the antenna under test against a known standard antenna, which has a calibrated gain, is technically known as a ***gain transfer*** technique. Another method for measuring gain is the 3 anten-

nas method, where the transmitted and received power at the antenna terminals is measured between three arbitrary antennas at a known fixed distance.

Radiation Pattern

The ***radiation pattern*** or ***antenna pattern*** describes the relative strength of the radiated field in various directions from the antenna, at a constant distance. The radiation pattern is a reception pattern as well, since it also describes the receiving properties of the antenna. The radiation pattern is three-dimensional, but usually the measured radiation patterns are a two-dimensional slice of the three-dimensional pattern, in the horizontal or vertical planes. These pattern measurements are presented in either a ***rectangular*** or a ***polar*** format. The following figure shows a rectangular plot presentation of a typical ten-element Yagi. The detail is good but it is difficult to visualize the antenna behavior in different directions.

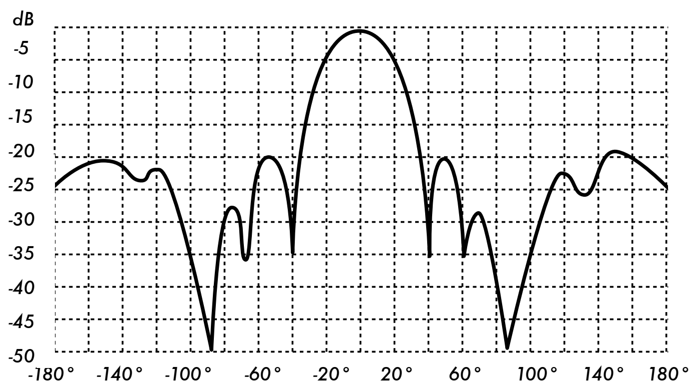


Figure 4.4: A rectangular plot of a yagi radiation pattern.

Polar coordinate systems are used almost universally. In the polar-coordinate graph, points are located by projection along a rotating axis (radius) to an intersection with one of several concentric circles. The following is a polar plot of the same 10 element Yagi antenna.

Polar coordinate systems may be divided generally in two classes: ***linear*** and ***logarithmic***. In the linear coordinate system, the concentric circles are equally spaced, and are graduated. Such a grid may be used to prepare a linear plot of the power contained in the signal. For ease of comparison, the equally spaced concentric circles may be replaced with appropriately placed circles representing the decibel response, referenced to 0 dB at the outer edge of the plot. In this kind of plot the minor lobes are suppressed. Lobes with peaks more than 15 dB or so below the main lobe disappear because of their small size. This grid enhances plots in which the antenna has a high directivity and small minor lobes. The voltage of the signal, rather than the power, can also be plotted on a linear coordinate system. In this case, too,

the directivity is enhanced and the minor lobes suppressed, but not in the same degree as in the linear power grid.

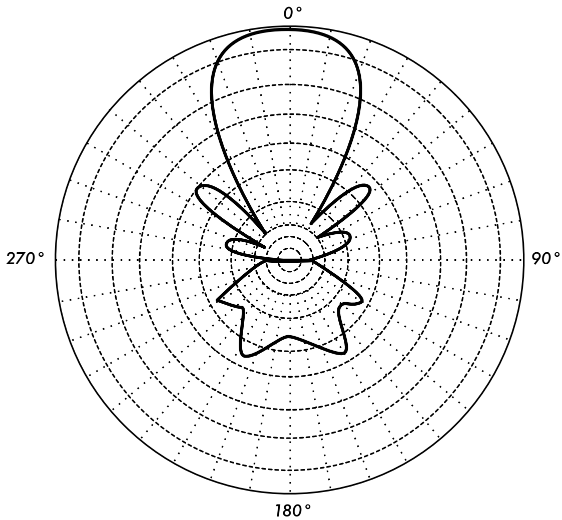


Figure 4.5: A linear polar plot of the same yagi.

In the logarithmic polar coordinate system the concentric grid lines are spaced periodically according to the logarithm of the voltage in the signal. Different values may be used for the logarithmic constant of periodicity, and this choice will have an effect on the appearance of the plotted patterns. Generally the 0 dB reference for the outer edge of the chart is used. With this type of grid, lobes that are 30 or 40 dB below the main lobe are still distinguishable. The spacing between points at 0 dB and at -3 dB is greater than the spacing between -20 dB and -23 dB, which is greater than the spacing between -50 dB and -53 dB. The spacing thus correspond to the relative significance of such changes in antenna performance.

A modified logarithmic scale emphasizes the shape of the major beam while compressing very low-level (>30 dB) sidelobes towards the center of the pattern. This is shown in **Figure 4.6**.

There are two kinds of radiation pattern: ***absolute*** and ***relative***. Absolute radiation patterns are presented in absolute units of field strength or power. Relative radiation patterns are referenced in relative units of field strength or power. Most radiation pattern measurements are relative to the isotropic antenna, and the gain transfer method is then used to establish the absolute gain of the antenna.

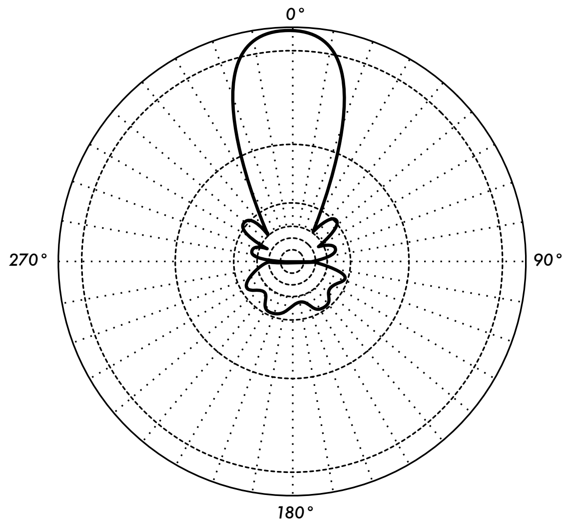


Figure 4.6: The logarithmic polar plot

The radiation pattern in the region close to the antenna is not the same as the pattern at large distances. The term near-field refers to the field pattern that exists close to the antenna, while the term far-field refers to the field pattern at large distances. The far-field is also called the radiation field, and is what is most commonly of interest. Ordinarily, it is the radiated power that is of interest, and so antenna patterns are usually measured in the far-field region. For pattern measurement it is important to choose a distance sufficiently large to be in the far-field, well out of the near-field. The minimum permissible distance depends on the dimensions of the antenna in relation to the wavelength. The accepted formula for this distance is:

$$r_{min} = \frac{2d^2}{\lambda}$$

where r_{min} is the minimum distance from the antenna, d is the largest dimension of the antenna, and λ is the wavelength.

Beamwidth

An antenna's ***beamwidth*** is usually understood to mean the half-power beamwidth. The peak radiation intensity is found, and then the points on either side of the peak which represent half the power of the peak intensity are located. The angular distance between the half power points is defined as the beamwidth. Half the power expressed in decibels is -3dB, so the half power beamwidth is sometimes referred to as the 3dB beamwidth. Both horizontal and vertical beamwidth are usually considered.

Assuming that most of the radiated power is not divided into sidelobes, then the directive gain is inversely proportional to the beamwidth: as the beamwidth decreases, the directive gain increases.

Sidelobes

No antenna is able to radiate all the energy in one preferred direction. Some is inevitably radiated in other directions. These smaller peaks are referred to as ***sidelobes***, commonly specified in dB down from the main lobe.

Nulls

In an antenna radiation pattern, a ***null*** is a zone in which the effective radiated power is at a minimum. A null often has a narrow directivity angle compared to that of the main beam. Thus, the null is useful for several purposes, such as suppression of interfering signals in a given direction.

Polarization

Polarization is defined as the orientation of the electric field of an electromagnetic wave. Polarization is in general described by an ellipse. Two special cases of elliptical polarization are ***linear polarization*** and ***circular polarization***. The initial polarization of a radio wave is determined by the antenna.

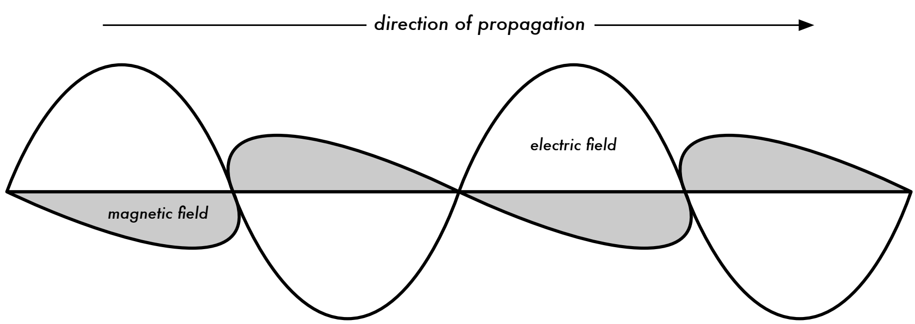


Figure 4.7: The electrical wave is perpendicular to magnetic wave, both of which are perpendicular to the direction of propagation.

With linear polarization, the electric field vector stays in the same plane all the time. The electric field may leave the antenna in a vertical orientation, a horizontal orientation, or at some angle between the two. ***Vertically polarized*** radiation is somewhat less affected by reflections over the transmission path. Omnidirectional antennas always have vertical polarization. With ***horizontal polarization***, such reflections cause variations in received signal strength. Horizontal antennas are less likely to pick up man-made interference, which ordinarily is vertically polarized.

In circular polarization the electric field vector appears to be rotating with circular motion about the direction of propagation, making one full turn for each RF cycle. This rotation may be right-hand or left-hand. Choice of polarization is one of the design choices available to the RF system designer.

Polarization Mismatch

In order to transfer maximum power between a transmit and a receive antenna, both antennas must have the same spatial orientation, the same polarization sense, and the same axial ratio.

When the antennas are not aligned or do not have the same polarization, there will be a reduction in power transfer between the two antennas. This reduction in power transfer will reduce the overall system efficiency and performance.

When the transmit and receive antennas are both linearly polarized, physical antenna misalignment will result in a polarization mismatch loss, which can be determined using the following formula:

$$\text{Loss (dB)} = 20 \log (\cos \theta)$$

...where θ is the difference in alignment angle between the two antennas. For 15° the loss is approximately 0.3dB, for 30° we lose 1.25dB, for 45° we lose 3dB and for 90° we have an infinite loss.

In short, the greater the mismatch in polarization between a transmitting and receiving antenna, the greater the apparent loss. In the real world, a 90° mismatch in polarization is quite large but not infinite. Some antennas, such as yagis or can antennas, can be simply rotated 90° to match the polarization of the other end of the link. You can use the polarization effect to your advantage on a point-to-point link. Use a monitoring tool to observe interference from adjacent networks, and rotate one antenna until you see the lowest received signal. Then bring your link online and orient the other end to match polarization. This technique can sometimes be used to build stable links, even in noisy radio environments.

Front-to-back ratio

It is often useful to compare the ***front-to-back ratio*** of directional antennas. This is the ratio of the maximum directivity of an antenna to its directivity in the opposite direction. For example, when the radiation pattern is plotted on a relative dB scale, the front-to-back ratio is the difference in dB between the level of the maximum radiation in the forward direction and the level of radiation at 180 degrees.

This number is meaningless for an omnidirectional antenna, but it gives you an idea of the amount of power directed forward on a very directional antenna.

Types of Antennas

A classification of antennas can be based on:

- **Frequency and size**. Antennas used for HF are different from antennas used for VHF, which in turn are different from antennas for microwave. The wavelength is different at different frequencies, so the antennas must be different in size to radiate signals at the correct wavelength. We are particularly interested in antennas working in the microwave range, especially in the 2.4 GHz and 5 GHz frequencies. At 2.4 GHz the wavelength is 12.5 cm, while at 5 GHz it is 6 cm.
- **Directivity.** Antennas can be omnidirectional, sectorial or directive. ***Omnidirectional antennas*** radiate roughly the same pattern all around the antenna in a complete 360° pattern. The most popular types of omnidirectional antennas are the ***dipole*** and the ***ground plane***. ***Sectorial antennas*** radiate primarily in a specific area. The beam can be as wide as 180 degrees, or as narrow as 60 degrees. ***Directional*** or ***directive antennas*** are antennas in which the beamwidth is much narrower than in sectorial antennas. They have the highest gain and are therefore used for long distance links. Types of directive antennas are the Yagi, the biquad, the horn, the helicoidal, the patch antenna, the parabolic dish, and many others.
- **Physical construction.** Antennas can be constructed in many different ways, ranging from simple wires, to parabolic dishes, to coffee cans.

When considering antennas suitable for 2.4 GHz WLAN use, another classification can be used:

- **Application**. Access points tend to make point-to-multipoint networks, while remote links are point-to-point. Each of these suggest different types of antennas for their purpose. Nodes that are used for multipoint access will likely use omni antennas which radiate equally in all directions, or sectorial antennas which focus into a small area. In the point-to-point case, antennas are used to connect two single locations together. Directive antennas are the primary choice for this application.

A brief list of common type of antennas for the 2.4 GHz frequency is presented now, with a short description and basic information about their characteristics.

1/4 wavelength ground plane

The 1⁄4 wavelength ground plane antenna is very simple in its construction and is useful for communications when size, cost and ease of construction are important. This antenna is designed to transmit a vertically polarized signal. It consists of a 1⁄4 wave element as half-dipole and three or four 1⁄4 wavelength ground elements bent 30 to 45 degrees down. This set of elements, called radials, is known as a ground plane.

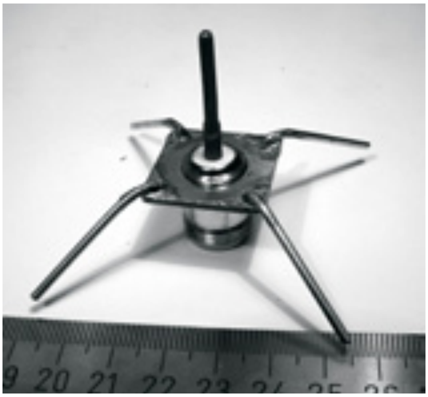


Figure 4.8: Quarter wavelength ground plane antenna.

This is a simple and effective antenna that can capture a signal equally from all directions. To increase the gain, the signal can be flattened out to take away focus from directly above and below, and providing more focus on the horizon. The vertical beamwidth represents the degree of flatness in the focus. This is useful in a Point-to-Multipoint situation, if all the other antennas are also at the same height. The gain of this antenna is in the order of 2 - 4 dBi.

Yagi antenna

A basic Yagi consists of a certain number of straight elements, each measuring approximately half wavelength. The driven or active element of a Yagi is the equivalent of a center-fed, half-wave dipole antenna. Parallel to the driven element, and approximately 0.2 to 0.5 wavelength on either side of it, are straight rods or wires called reflectors and directors, or simply passive elements. A reflector is placed behind the driven element and is slightly longer than half wavelength; a director is placed in front of the driven element and is slightly shorter than half wavelength. A typical Yagi has one reflector and one or more directors. The antenna propagates electromagnetic field energy in the direction running from the driven element toward the directors, and is most sensitive to incoming electromagnetic field energy in this same direction. The more directors a Yagi has, the greater the gain. As more direc-

tors are added to a Yagi, it therefore becomes longer. Following is the photo of a Yagi antenna with 6 directors and one reflector.

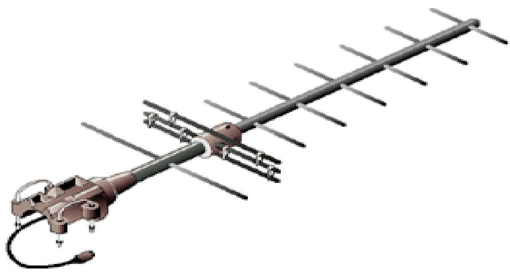


Figure 4.9: A Yagi antenna.

Yagi antennas are used primarily for Point-to-Point links, have a gain from 10 to 20 dBi and a horizontal beamwidth of 10 to 20 degrees.

Horn

The horn antenna derives its name from the characteristic flared appearance. The flared portion can be square, rectangular, cylindrical or conical. The direction of maximum radiation corresponds with the axis of the horn. It is easily fed with a waveguide, but can be fed with a coaxial cable and a proper transition.

Figure 4.10: Feed horn made from a food can.

Horn antennas are commonly used as the active element in a dish antenna. The horn is pointed toward the center of the dish reflector. The use of a horn, rather than a dipole antenna or any other type of antenna, at the focal point of the dish minimizes loss of energy around the edges of the dish reflector. At 2.4 GHz, a simple horn antenna made with a tin can has a gain in the order of 10 - 15 dBi.

Parabolic Dish

Antennas based on parabolic reflectors are the most common type of directive antennas when a high gain is required. The main advantage is that they can be made to have gain and directivity as large as required. The main disadvantage is that big dishes are difficult to mount and are likely to have a large windage.

Figure 4.11: A solid dish antenna.

Dishes up to one meter are usually made from solid material. Aluminum is frequently used for its weight advantage, its durability and good electrical characteristics. Windage increases rapidly with dish size and soon becomes a severe problem. Dishes which have a reflecting surface that uses an open mesh are frequently used. These have a poorer front-to-back ratio, but are safer to use and easier to build. Copper, aluminum, brass, galvanized steel and iron are suitable mesh materials.

BiQuad

The BiQuad antenna is simple to build and offers good directivity and gain for Point-to-Point communications. It consists of a two squares of the same size of 1⁄4 wavelength as a radiating element and of a metallic plate or grid as reflector. This antenna has a beamwidth of about 70 degrees and a gain in the order of 10-12 dBi. It can be used as stand-alone antenna or as feeder for a Parabolic Dish. The polarization is such that looking at the antenna from the front, if the squares are placed side by side the polarization is vertical.

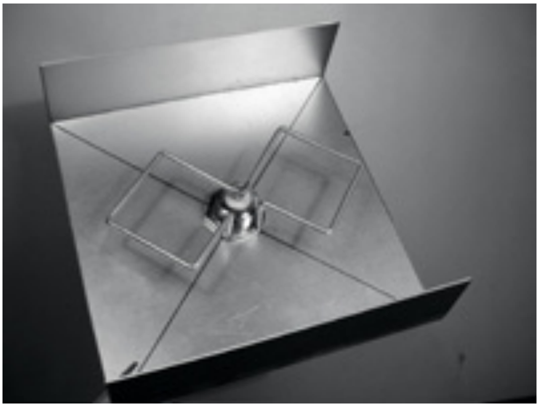


Figure 4.12: The BiQuad.

Other Antennas

Many other types of antennas exist and new ones are created following the advances in technology.

- Sector or Sectorial antennas: they are widely used in cellular telephony infrastructure and are usually built adding a reflective plate to one or more phased dipoles. Their horizontal beamwidth can be as wide as 180 degrees, or as narrow as 60 degrees, while the vertical is usually much narrower. Composite antennas can be built with many Sectors to cover a wider horizontal range (multisectorial antenna).
- Panel or Patch antennas: they are solid flat panels used for indoor coverage, with a gain up to 20 dB.

Reflector theory

The basic property of a perfect parabolic reflector is that it converts a spherical wave irradiating from a point source placed at the focus into a plane wave. Conversely, all the energy received by the dish from a distant source is reflected to a single point at the focus of the dish. The position of the focus, or focal length, is given by:

$$f = \frac{D^2}{16 \times c}$$

...where D is the dish diameter and c is the depth of the parabola at its center.

The size of the dish is the most important factor since it determines the maximum gain that can be achieved at the given frequency and the resulting beamwidth. The gain and beamwidth obtained are given by:

$$\text{Gain} = \frac{(\pi \times D)^2}{\lambda^2} \times n$$

$$\text{Beamwidth} = \frac{70\ \lambda}{D}$$

...where D is the dish diameter and n is the efficiency. The efficiency is determined mainly by the effectiveness of illumination of the dish by the feed, but also by other factors. Each time the diameter of a dish is doubled, the gain is four times, or 6 dB, greater. If both stations double the size of their dishes, signal strength can be increased of 12 dB, a very substantial gain. An efficiency of 50% can be assumed when hand-building the antenna.

The ratio f / D (focal length/diameter of the dish) is the fundamental factor governing the design of the feed for a dish. The ratio is directly related to the beamwidth of the feed necessary to illuminate the dish effectively. Two dishes of the same diameter but different focal lengths require different design of feed if both are to be illuminated efficiently. The value of 0.25 corresponds to the common focal-plane dish in which the focus is in the same plane as the rim of the dish.

Amplifiers

As mentioned earlier, antennas do not actually create power. They simply direct all available power into a particular pattern. By using a ***power amplifier***, you can use DC power to augment your available signal. An amplifier connects between the radio transmitter and the antenna, and has an additional lead that connects to a power source. Amplifiers are available that work at 2.4 GHz, and can add several Watts of power to your transmission. These devices sense when an attached radio is transmitting, and quickly power up and amplify the signal. They then switch off again when transmission ends. When receiving, they also add amplification to the signal before sending it to the radio.

Unfortunately, simply adding amplifiers will not magically solve all of your networking problems. We do not discuss power amplifiers at length in this book because there are a number of significant drawbacks to using them:

- **They are expensive**. Amplifiers must work at relatively wide bandwidths at 2.4 GHz, and must switch quickly enough to work for Wi-Fi applications.

These amplifiers do exist, but they tend to cost several hundred dollars per unit.

- **You will need at least two**. Whereas antennas provide reciprocal gain that benefits both sides of a connection, amplifiers work best at amplifying a transmitted signal. If you only add an amplifier to one end of a link with insufficient antenna gain, it will likely be able to be heard but will not be able to hear the other end.
- **They provide no additional directionality.** Adding antenna gain provides both gain and directionality benefits to both ends of the link. They not only improve the available amount of signal, but tend to reject noise from other directions. Amplifiers blindly amplify both desired and interfering signals, and can make interference problems worse.
- **Amplifiers generate noise for other users of the band.** By increasing your output power, you are creating a louder source of noise for other users of the unlicensed band. This may not be much of an issue today in rural areas, but it can cause big problems in populated areas. Conversely, adding antenna gain will improve your link and can actually decrease the noise level for your neighbors.
- **Using amplifiers probably isn't legal.** Every country imposes power limits on use of unlicensed spectrum. Adding an antenna to a highly amplified signal will likely cause the link to exceed legal limits.

Using amplifiers is often compared to the inconsiderate neighbor who wants to listen to the radio outside their home, and so turns it up to full volume. They might even "improve" reception by pointing their speakers out the window. While they may now be able to hear the radio, so must everyone else on the block. This approach may scale to exactly one user, but what happens when the neighbors decide to do the same thing with their radios? Using amplifiers for a wireless link causes roughly the same effect at 2.4 GHz. Your link may "work better" for the moment, but you will have problems when other users of the band decide to use amplifiers of their own.

By using higher gain antennas rather than amplifiers, you avoid all of these problems. Antennas cost far less than amps, and can improve a link simply by changing the antenna on one end. Using more sensitive radios and good quality cable also helps significantly on long distance shots. These techniques are unlikely to cause problems for other users of the band, and so we recommend pursuing them before adding amplifiers.

Practical antenna designs

The cost of 2.4 GHz antennas has fallen dramatically since the introduction of 802.11b. Innovative designs use simpler parts and fewer materials to achieve

impressive gain with relatively little machining. Unfortunately, availability of good antennas is still limited in many areas of the world, and importing them can be prohibitively expensive. While actually designing an antenna can be a complex and error-prone process, constructing antennas from locally available components is very straightforward, and can be a lot of fun. We present four practical antenna designs that can be built for very little money.

USB dongle as dish feed

Possibly the simplest antenna design is the use of a parabola to direct the output of a USB wireless device (known in networking circles as a ***USB dongle***). By placing the internal dipole antenna present in USB wireless dongles at the focus of a parabolic dish, you can provide significant gain without the need to solder or even open the wireless device itself. Many kinds of parabolic dishes will work, including satellite dishes, television antennas, and even metal cookware (such as a wok, round lid, or strainer). As a bonus, inexpensive and lossless USB cable is then used to feed the antenna, eliminating the need for expensive coaxial cable or Heliax.

To build a USB dongle parabolic, you will need to find the orientation and location of the dipole inside the dongle. Most devices orient the dipole to be parallel with the short edge of the dongle, but some will mount the dipole perpendicular to the short edge. You can either open the dongle and look for yourself, or simply try the dongle in both positions to see which provides more gain.

To test the antenna, point it at an access point several meters away, and connect the USB dongle to a laptop. Using the laptop's client driver or a tool such as Netstumbler (see **Chapter 6**), observe the received signal strength of the access point. Now, slowly move the dongle in relation to the parabolic while watching the signal strength meter. You should see a significant improvement in gain (20 dB or more) when you find the proper position. The proper position will vary depending on the shape of the parabola and the construction of the USB dongle. Try various positions while watching your signal strength meter until you find the optimum location.

Once the best location is found, securely fix the dongle in place. You will need to waterproof the dongle and cable if the antenna is used outdoors. Use a silicone compound or a piece of PVC tubing to seal the electronics against the weather. Many USB-fed parabolic designs and ideas are documented online at *http://www.usbwifi.orcon.net.nz/* .

Collinear omni

This antenna is very simple to build, requiring just a piece of wire, an N socket and a square metallic plate. It can be used for indoor or outdoor point-to-multipoint short distance coverage. The plate has a hole drilled in the mid-

dle to accommodate an N type chassis socket that is screwed into place. The wire is soldered to the center pin of the N socket and has coils to separate the active phased elements. Two versions of the antenna are possible: one with two phased elements and two coils and another with four phased elements and four coils. For the short antenna the gain will be around 5 dBi, while the long one with four elements will have 7 to 9 dBi of gain. We are going to describe how to build the long antenna only.

Parts list and tools required

- One screw-on N-type female connector
- 50 cm of copper or brass wire of 2 mm of diameter
- 10x10 cm or greater square metallic plate

Figure 4.13: 10 cm x 10 cm aluminum plate.

- Ruler
- Pliers
- File
- Soldering iron and solder
- Drill with a set of bits for metal (including a 1.5 cm diameter bit)
- A piece of pipe or a drill bit with a diameter of 1 cm
- Vice or clamp
- Hammer
- Spanner or monkey wrench

Construction

1. Straighten the wire using the vice.

Figure 4.14: Make the wire as straight as you can.

2. With a marker, draw a line at 2.5 cm starting from one end of the wire. On this line, bend the wire at 90 degrees with the help of the vice and of the hammer.

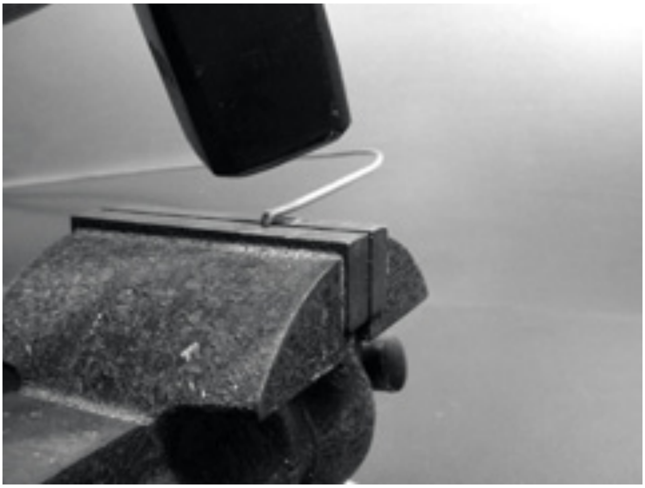


Figure 4.15: Gently tap the wire to make a sharp bend.

3. Draw another line at a distance of 3.6 cm from the bend. Using the vice and the hammer, bend once again the wire over this second line at 90 degrees, in the opposite direction to the first bend but in the same plane. The wire should look like a 'Z'.

Figure 4.16: Bend the wire into a "Z" shape.

4. We will now twist the 'Z' portion of the wire to make a coil with a diameter of 1 cm. To do this, we will use the pipe or the drill bit and curve the wire around it, with the help of the vice and of the pliers.

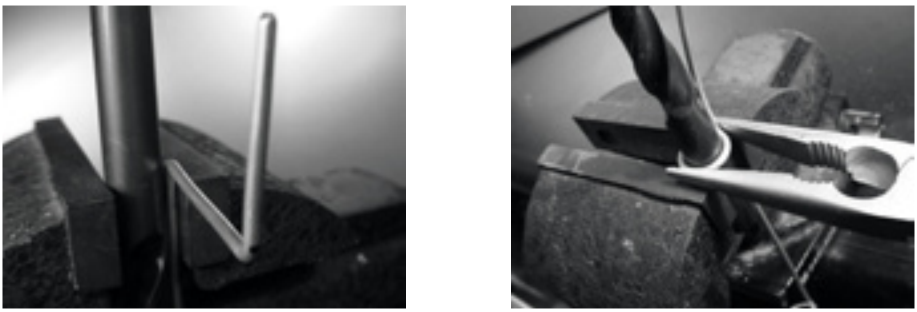


Figure 4.17: Bend the wire around the drill bit to make a coil.

The coil will look like this:

Figure 4.18: The completed coil.

5. You should make a second coil at a distance of 7.8 cm from the first one. Both coils should have the same turning direction and should be placed on the same side of the wire. Make a third and a fourth coil following the

same procedure, at the same distance of 7.8 cm one from each other. Trim the last phased element at a distance of 8.0 cm from the fourth coil.

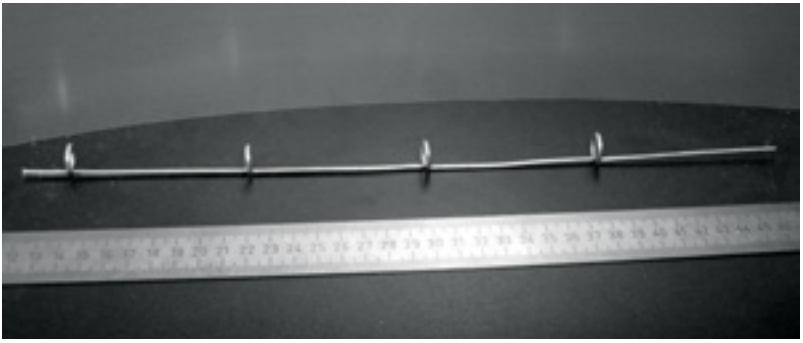


Figure 4.19: Try to keep it as straight possible.

If the coils have been made correctly, it should now be possible to insert a pipe through all the coils as shown.

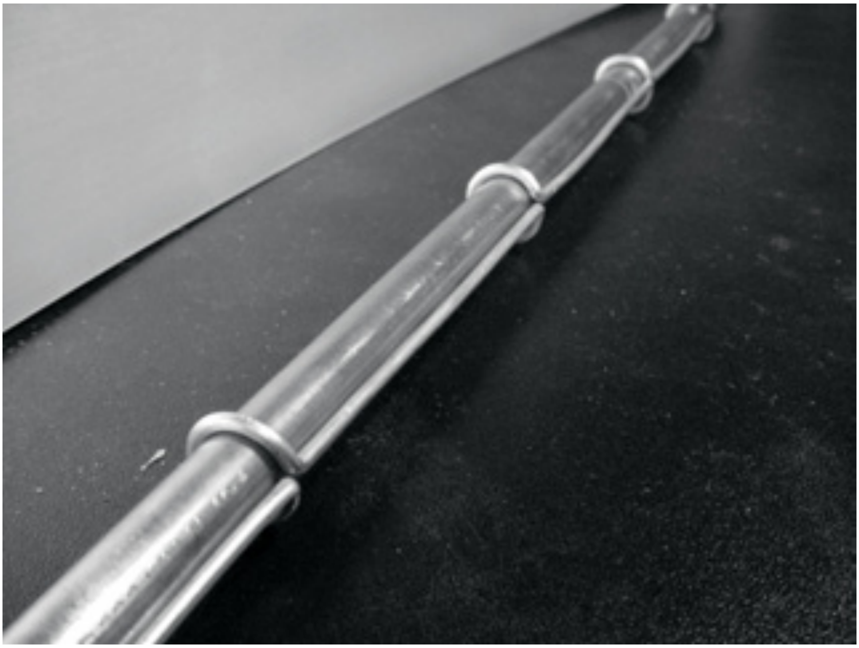
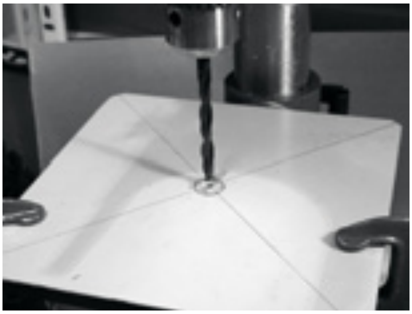


Figure 4.20: Inserting a pipe can help to straighten the wire.

6. With a marker and a ruler, draw the diagonals on the metallic plate, finding its center. With a small diameter drill bit, make a pilot hole at the center of the plate. Increase the diameter of the hole using bits with an increasing diameter.



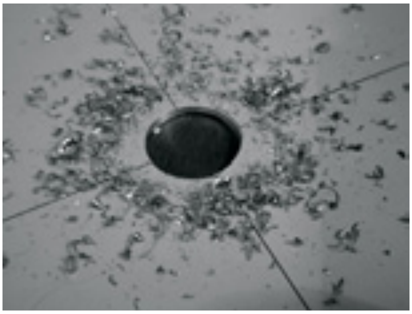


Figure 4.21: Drilling the hole in the metal plate.

The hole should fit the N connector exactly. Use a file if needed.

Figure 4.22: The N connector should fit snugly in the hole.

7. To have an antenna impedance of 50 Ohms, it is important that the visible surface of the internal insulator of the connector (the white area around the central pin) is at the same level as the surface of the plate. For this reason, cut 0.5 cm of copper pipe with an external diameter of 2 cm, and place it between the connector and the plate.

Figure 4.23: Adding a copper pipe spacer helps to match the impedance of the antenna to 50 Ohms.

8. Screw the nut to the connector to fix it firmly on the plate using the spanner.

Figure 4.24: Secure the N connector tightly to the plate.

9. Smooth with the file the side of the wire which is 2.5 cm long, from the first coil. Tin the wire for around 0.5 cm at the smoothed end helping yourself with the vice.

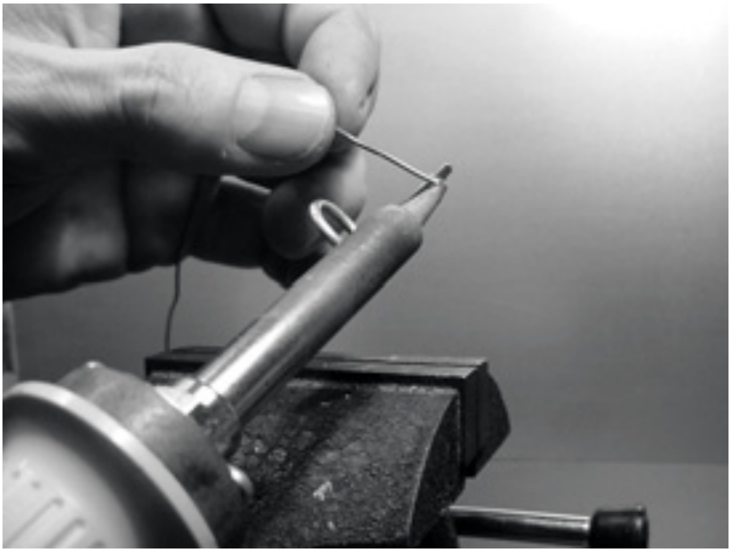


Figure 4.25: Add a little solder to the end of the wire to "tin" it prior to soldering.

10. With the soldering iron, tin the central pin of the connector. Keeping the wire vertical with the pliers, solder its tinned side in the hole of the central pin. The first coil should be at 3.0 cm from the plate.

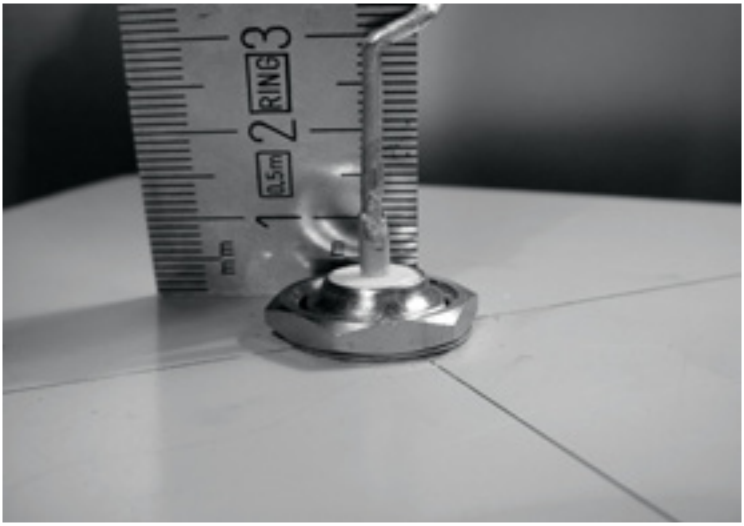


Figure 4.26: The first coil should start 3.0 cm from the surface of the plate.

11. We are now going to stretch the coils extending the total vertical length of the wire. Using the use the vice and the pliers, you should pull the cable so that the final length of the coil is of 2.0 cm.

Figure 4.27: Stretching the coils. Be very gentle and try not to scrape the surface of the wire with the pliers.

12. Repeat the same procedure for the other three coils, stretching their length to 2.0 cm.

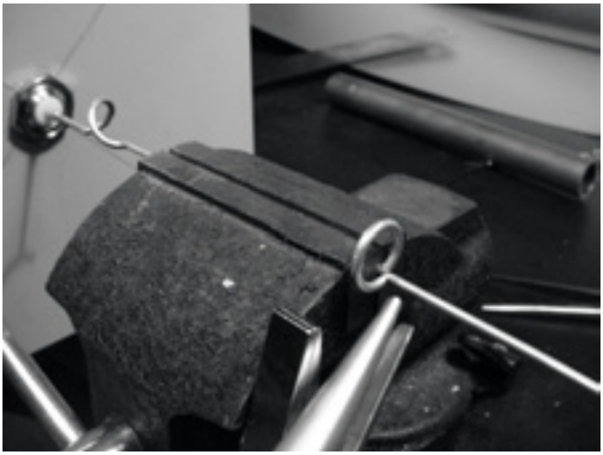


Figure 4.28: Repeat the stretching procedure for all of the remaining coils.

13. At the end the antenna should measure 42.5 cm from the plate to the top.

Figure 4.29: The finished antenna should be 42.5 cm from the plate to the end of the wire.

14. If you have a spectrum analyzer with a tracking generator and a directional coupler, you can check the curve of the reflected power of the antenna. The picture below shows the display of the spectrum analyzer.

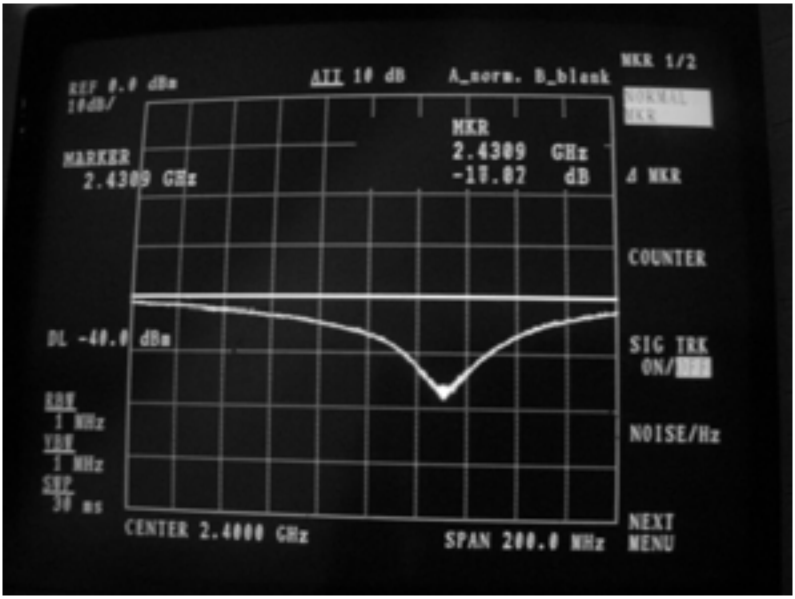


Figure 4.30: A spectrum plot of the reflected power of the collinear omni.

If you intend to use this antenna outside, you will need to weatherproof it. The simplest method is to enclose the whole thing in a large piece of PVC pipe closed with caps. Cut a hole at the bottom for the transmission line, and seal the antenna shut with silicone or PVC glue.

Cantenna

The waveguide antenna, sometimes called a Cantenna, uses a tin can as a waveguide and a short wire soldered on an N connector as a probe for coaxial-cable-to-waveguide transition. It can be easily built at just the price of the connector, recycling a food, juice, or other tin can. It is a directional antenna, useful for short to medium distance point-to-point links. It may be also used as a feeder for a parabolic dish or grid.

Not all cans are good for building an antenna because there are dimensional constraints.

1. The acceptable values for the diameter D of the feed are between 0.60 and 0.75 wavelength in air at the design frequency. At 2.44 GHz the wavelength λ is 12.2 cm, so the can diameter should be in the range of 7.3 - 9.2 cm.
2. The length L of the can preferably should be at least 0.75 λ_G , where λ_G is the guide wavelength and is given by:

$$\lambda_G = \frac{\lambda}{\mathrm{sqrt}(1 - (\lambda / 1.706D)^2)}$$

For D = 7.3 cm, we need a can of at least 56.4 cm, while for D = 9.2 cm we need a can of at least 14.8 cm. Generally the smaller the diameter, the longer the can should be. For our example, we will use oil cans that have a diameter of 8.3 cm and a height of about 21 cm.

3. The probe for coaxial cable to waveguide transition should be positioned at a distance S from the bottom of the can, given by:

$$S = 0.25\ \lambda_G$$

Its length should be 0.25 λ, which at 2.44 GHz corresponds to 3.05 cm.

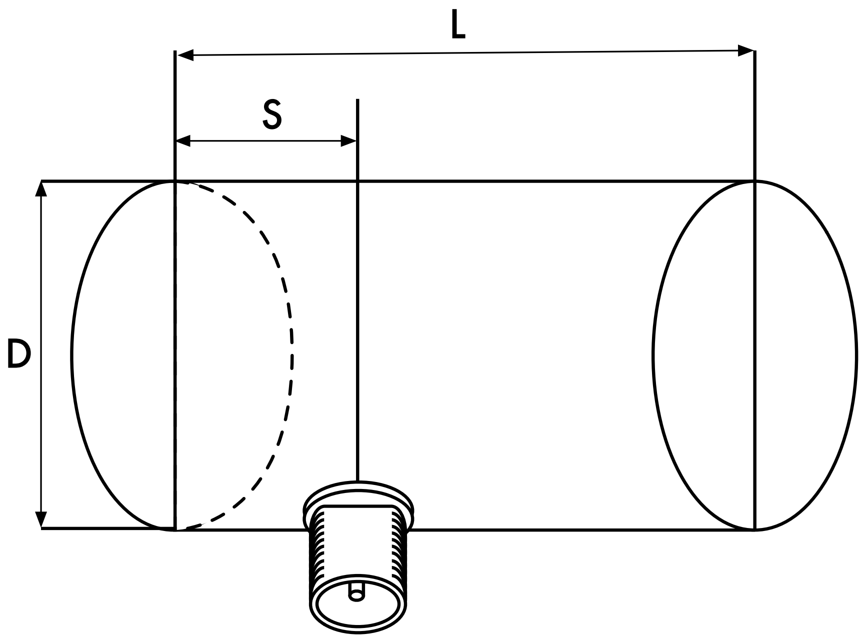


Figure 4.31: Dimensional constraints on the cantenna

The gain for this antenna will be in the order of 10 to 14 dBi, with a beam-width of around 60 degrees.

Figure 4.32: The finished cantenna.

Parts list

- one screw-on N-type female connector
- 4 cm of copper or brass wire of 2 mm of diameter
- an oil can of 8.3 cm of diameter and 21 cm of height

Figure 4.33: Parts needed for the can antenna.

Tools required

- Can opener
- Ruler
- Pliers
- File
- Soldering iron
- Solder
- Drill with a set of bits for metal (with a 1.5 cm diameter bit)
- Vice or clamp
- Spanner or monkey wrench
- Hammer
- Punch

Construction

1. With the can opener, carefully remove the upper part of the can.

Figure 4.34: Be careful of sharp edges when opening the can.

The circular disk has a very sharp edge. Be careful when handling it! Empty the can and wash it with soap. If the can contained pineapple, cookies, or some other tasty treat, have a friend serve the food.

2. With the ruler, measure 6.2 cm from the bottom of the can and draw a point. Be careful to measure from the inner side of the bottom. Use a punch (or a small drill bit or a Phillips screwdriver) and a hammer to mark the point. This makes it easier to precisely drill the hole. Be careful not to

change the shape of the can doing this by inserting a small block of wood or other object in the can before tapping it.

Figure 4.35: Mark the hole before drilling.

3. With a small diameter drill bit, make a hole at the center of the plate. Increase the diameter of the hole using bits with an increasing diameter. The hole should fit exactly the N connector. Use the file to smooth the border of the hole and to remove the painting around it in order to ensure a better electrical contact with the connector.

Figure 4.36: Carefully drill a pilot hole, then use a larger bit to finish the job.

4. Smooth with the file one end of the wire. Tin the wire for around 0.5 cm at the same end helping yourself with the vice.

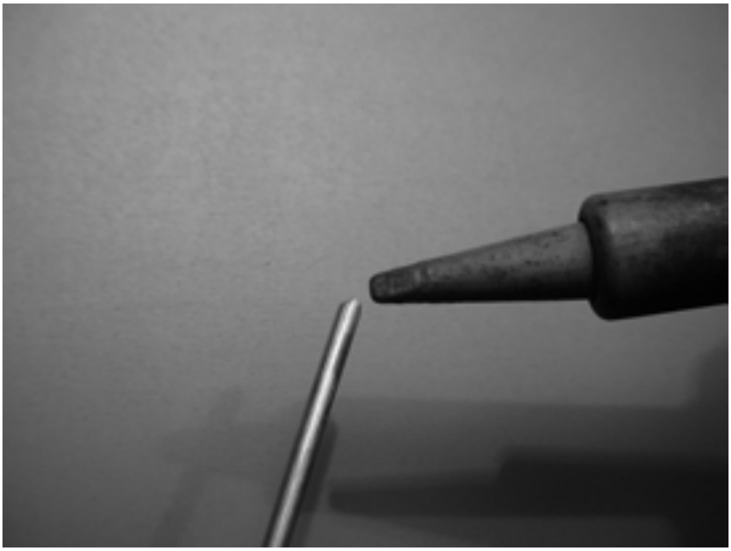


Figure 4.37: Tin the end of the wire before soldering.

5. With the soldering iron, tin the central pin of the connector. Keeping the wire vertical with the pliers, solder its tinned side in the hole of the central pin.

Figure 4.38: Solder the wire to the gold cup on the N connector.

6. Insert a washer and gently screw the nut onto the connector. Trim the wire at 3.05 cm measured from the bottom part of the nut.

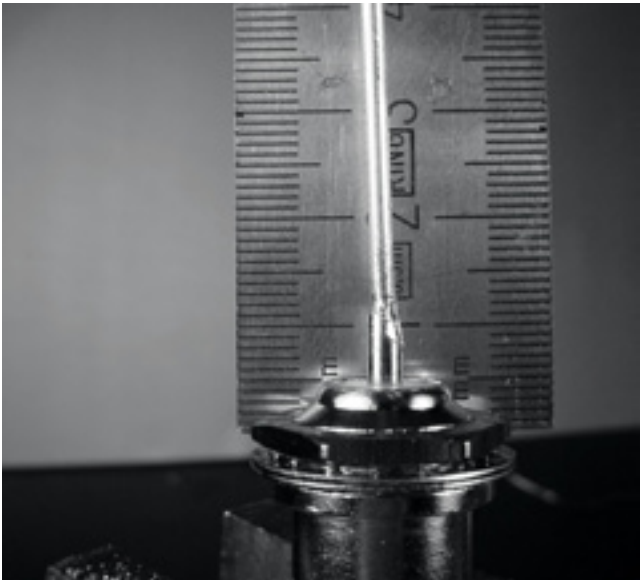


Figure 4.39: The length of the wire is critical.

7. Unscrew the nut from the connector, leaving the washer in place. Insert the connector into the hole of the can. Screw the nut on the connector from inside the can.

Figure 4.40: Assemble the antenna.

8. Use the pliers or the monkey wrench to screw firmly the nut on the connector. You are done!

Figure 4.41: Your finished cantenna.

As with the other antenna designs, you should make a weatherproof enclosure for the antenna if you wish to use it outdoors. PVC works well for the can antenna. Insert the entire can in a large PVC tube, and seal the ends with caps and glue. You will need to drill a hole in the side of the tube to accommodate the N connector on the side of the can.

Cantenna as dish feed

As with the USB dongle parabolic, you can use the cantenna design as a feeder for significantly higher gain. Mount the can on the parabolic with the opening of the can pointed at the center of the dish. Use the technique described in the USB dongle antenna example (watching signal strength changes over time) to find the optimum location of the can for the dish you are using.

By using a well-built cantenna with a properly tuned parabolic, you can achieve an overall antenna gain of 30dBi or more. As the size of the parabolic increases, so does the potential gain and directivity of the antenna. With very large parabolas, you can achieve significantly higher gain.

For example, in 2005, a team of college students successfully established a link from Nevada to Utah in the USA. The link crossed a distance of over 200 kilometers! The wireless enthusiasts used a 3.5 meter satellite dish to establish an 802.11b link that ran at 11 Mbps, without using an amplifier. Details about this achievement can be found at *http://www.wifi-shootout.com/*

NEC2

NEC2 stands for ***Numerical Electromagnetics Code*** (version 2) and is a free antenna modeling package. NEC2 lets you build an antenna model in 3D, and then analyzes the antenna's electromagnetic response. It was developed more than ten years ago and has been compiled to run on many different computer systems. NEC2 is particularly effective for analyzing wire-grid models, but also has some surface patch modeling capability.

The antenna design is described in a text file, and then the model is built using this text description. An antenna described in NEC2 is given in two parts: its ***structure*** and a sequence of ***controls***. The structure is simply a numerical description of where the different parts of the antenna are located, and how the wires are connected up. The controls tell NEC where the RF source is connected. Once these are defined, the transmitting antenna is then modeled. Because of the reciprocity theorem the transmitting gain pattern is the same as the receiving one, so modeling the transmission characteristics is sufficient to understand the antenna's behavior completely.

A frequency or range of frequencies of the RF signal must be specified. The next important element is the character of the ground. The conductivity of the earth varies from place to place, but in many cases it plays a vital role in determining the antenna gain pattern.

To run NEC2 on Linux, install the NEC2 package from the URL below. To launch it, type **`nec2`** and enter the input and output filenames. It is also worth installing the **`xnecview`** package for structure verification and radiation pattern plotting. If all went well you should have a file containing the output. This can be broken up into various sections, but for a quick idea of what it represents a gain pattern can be plotted using xnecview. You should see the expected pattern, horizontally omnidirectional, with a peak at the optimum angle of takeoff. Windows and Mac versions are also available.

The advantage of NEC2 is that we can get an idea of how the antenna works before building it, and how we can modify the design in order to get the maximum gain. It is a complex tool and requires some research to learn how to use it effectively, but it is an invaluable tool for antenna designers.

NEC2 is available from *http://www.nec2.org/*

Online documentation can be obtained from the "Unofficial NEC Home Page" at *http://www.nittany-scientific.com/nec/* .

FPV FRENZY

Spreading the FPV addiction

Choosing the best 5.8 gHz FPV antennas

By Gulzaar — Leave a Comment

Using a proper FPV antenna is the deciding factor in whether or not you will have good reception and ultimately a good flying experience!

FPV antennas come in a few different types:

- Dipole
- Circular polarized
- Helical(only practical for receivers)
- Patch(only practical for receivers)

It's also important to know what kind of connector your fpv equipment has, and to match it to the connector on the antenna! There are two types of connectors: SMA and RP-SMA. One isn't necessarily better than the other, but it's just a matter of design. In SMA antennas, the female plug(the one that the other plug screws on to) has a hole, where the extruding wire from the SMA male plug goes in.

In RPSMA antennas, it's the other way around. When you buy your equipment, make sure to read what kind of

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- Dragonfly Battle Diversity Receiver for FPV Ground Stations

GET STARTED

connector your FPV transmitter and receiver has – it'll always be in the product description, and buy antennas that have the proper plugs.

A word of caution, though, and repeat after me:

> ***I WILL NEVER POWER MY FPV TRANSMITTER WITHOUT AN ANTENNA PLUGGED IN!***

If you power it up without an antenna, heat will build up in the transmitter and it'll burn up!

Best way to mount an antenna

In my earlier builds, I would mount the antenna and video transmitter by pushing the connector of the transmitter through a hole in the top plate of the frame, and then screwing the antenna down on to the connector, so it would be upright.

This is fine, except that if you land/crash upside down at a weird angle, there is a lot of force and tension at the connector itself and I've broken a few antennas/connectors this way.

I like to mount my antennas horizontally – the transmitter goes under the top plate(the connector on the transmitter will also be inside the top plate, not sticking out), and only half or 3/4 of the antenna sticks out from behind the copter. You can either leave it straight or bend it up a little.

This offers the most protection to the somewhat delicate connector, and doesn't really affect range in any way.

Back to antennas, though.

Dipole antennas

Note: The image is actually a 2.4 gHz antenna – a 5.8 gHz antenna will be smaller.

Dipole antennas, also known as rubber ducky antennas, are very simple – just some coax cable with a bit of metal casing on the end to transmit or receive the signal.

Rubber ducky antennas have very poor range, especially for multirotors, because they can only transmit if they are upright. So if you bank hard to the left or right, or try to do a flip, you'll lose signal.

These antennas are also very sensitive to multi-pathing, which is when the video signal bounces off of hard objects, so if you fly near a wall(or walls), you'll lose signal very quick.

Most FPV equipment comes with a rubber ducky antenna out of the box – but you won't be needing it.

Circular polarized antennas

Circular polarized antennas are three-or-four lobed antennas that give much better reception than dipole antennas. They are also known as skew-planar or omni-directional antennas, which means they can transmit and receive equally well in all directions, so no matter what the orientation of your multi-rotor is(up/down/left/right), you'll still get a good signal.

These antennas are also less susceptible to multi-pathing, so you can fly around walls and trees with better video quality.

There are two types of circular polarized antennas – right-hand and left-hand. Right-hand will only receive signal from a transmitter that's sending out a signal with a right-hand antenna and no other. The same goes for left-hand antennas.

Circular polarized antennas are the most common(for a good reason) antennas in multi-rotor FPV, and as such they come in many different designs.

There are cheap eBay/Chinese antennas, in which there’s just a connector, coax cable, and the three lobed or four lobed head. There is no protection for the cable or the head. These antennas are very cheap and functional – though their performance may vary every now and then, and the lobes will easily bend out of shape in a collision.

Note: I have since ditched the AOMWAY antennas for TBS and Foxeer antennas, in which the lobes are encased in nearly indestructible plastic.

My new favorite antenna is the Foxeer circular polarized. It gives performance which rivals or is even better than the AOMWAY or Fat Shark antennas, and the antenna is cased in nearly indestructible plastic. I've had some pretty rough crashes with these antennas and they are still holding up well.

To compare, I must have gone through at least 3 Fat Shark antennas and 3 AOMWAY antennas. At less than $10 per antenna, the value here is just amazing.

Buy two or three of these and they'll last a VERY long time.

Get the Foxeer antenna

The TBS Triumph is a premium version of the Foxeer antenna. One reason to prefer the TBS Triumph over the Foxeer is that the Triumph is significantly smaller than the Foxeer and there is less chance the lobe cover will hit the props. I've also managed to break Foxeer antennas but have never broken a TBS Triumph.

Pick up a TBS Triumph here

Aomway antennas

A very good brand of circular polarized antennas is Aomway. This is a Chinese brand, but the design is solid, with a protective coating on the wire and plastic reinforcement for the lobes. I ~~personally use~~ used to use the Aomway antennas, and was very happy with their performance. The coating lets me bend the antenna cable into whatever shape I need, and the plastic reinforcement protects the lobes when I crash.

Check prices and buy(RP-SMA)

Check prices and buy(SMA)

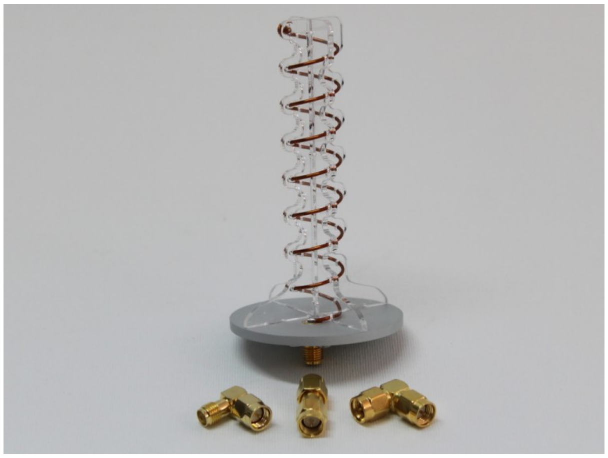
Pagoda Antennas

Pagoda antennas are upgraded versions of circular polarized antennas. They were originally developed by Marten Baart, and they have better range and clearer reception than normal circular polarized antennas. The designs were originally uploaded by Marten Baart for free, but they were a bit of a process to make and assemble.

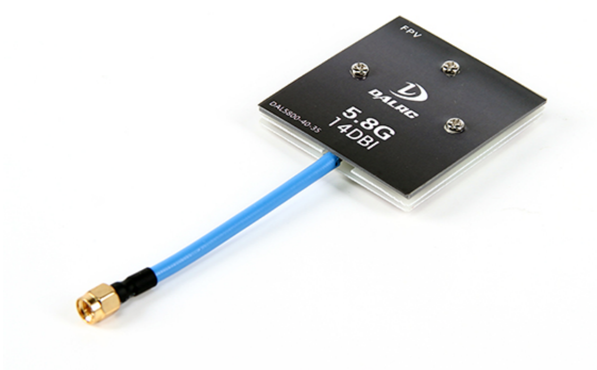
Many manufacturers make these antennas now, and they make them for quite cheap! The only disadvantage is that they are not *as* durable as the TBS Triumph, so you may see yourself replacing them a bit more often.

Pick up a Pagoda antenna from Banggood

Helical and patch antennas



Helical antennas are spring-shaped and have better reception than circular polarized antennas, but with a catch – they have a narrower beam, so they work best if the antenna is facing the transmitting antenna. Helical antennas do receive from the side and behind, but not as good as from the main beam.



Patch antennas are also directional – they work best when facing the transmitting antenna. If you had a longer range setup(lower than 5.8 ghz) and were flying a plane or multirotor straight away from you, patch and helical antennas are awesome.

But if you are flying a miniquad, in which you'll be whizzing around in all directions around your receiving antenna, helical and patch antennas alone are not a good idea.

However…

Directional antennas are EXCELLENT as second antennas on your diversity setup.

Diversity setups

Helical and patch antennas are excellent to use on diversity receivers. Diversity receivers do what the name suggests – instead of just one signal, they receive two signals(from two antennas), and then show you whichever the better signal is. They will also keep switching between whichever is the better frequency, and it'll be seamless, so you won't even realize it.

So if you have a diversity setup with one helical antenna and one circular polarized antenna, you'll see the helical image when flying in front and the circular polarized image when flying around and behind.

Diversity receivers are cheap for Fat Shark goggles now, such as the RX5808 which can be supercharged with better firmware.

In that case, I prefer the ImmersionRC patch antenna. Make sure you get the correct polarization(right hand or left hand)

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Filed Under: FPV Gear

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Wednesday, October 28, 2015

Hacking the Ten Tec Model 150A to extend its frequency range to 15 MHz

Be Amazed at the Wizardry of N6QW

Hacking the Ten Tec 150A SSB/CW transceiver to extend its range to 15 MHz

Three actions:

1. Modify the Final Amp Low Pass Filter
2. Modify the RxTx Mixer Band Pass Filter
3. Modify the Low Level Driver Low Pass Filter

All filter changes were simulated in LT Spice and I think it worked.

Pete N6QW

Posted by Pete Juliano at 7:33 PM 4 comments:

Saturday, October 24, 2015

Errata ~ Part 4 Simpleceiver

Errata in the Part 4 Discrete Audio Amplifier

One of the blog readers, W4JED contacted me regarding the "reversed polarity" of the output capacitor on the discrete component audio amplifier that appeared in Part 4. The schematic error would have most like caused a smoking of the capacitor (or a very loud bang followed by the smoking). Thank you for bringing it to my attention. The corrected schematic is shown below,

Digital Clock + Date

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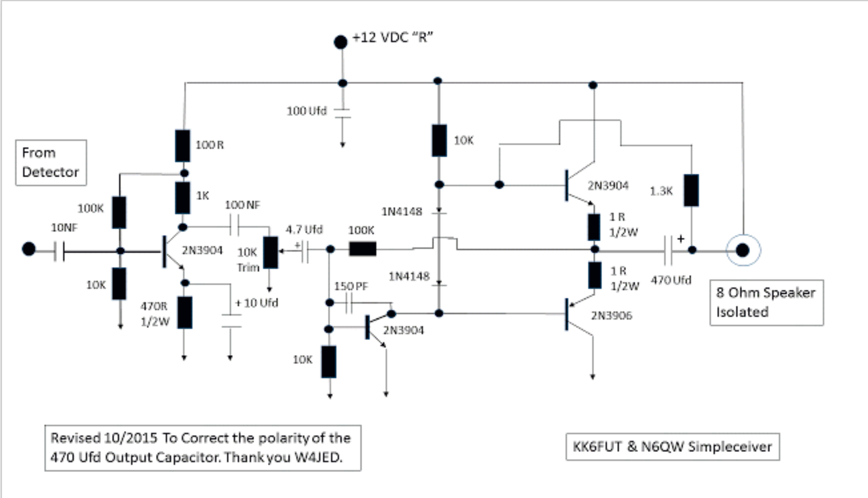
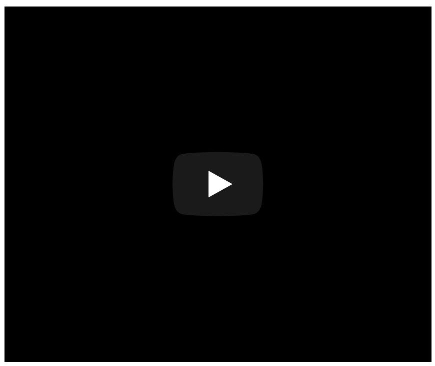
Pete N6QW



Soldering Surface mount can get a bit intense so what is needed is some loud music in the background to sort of calm the environment. For your listening pleasure some "Solderin Music"



Posted by Pete Juliano at 9:22 PM 1 comment:

Wednesday, October 21, 2015

Simpleceiver ~ Part 6

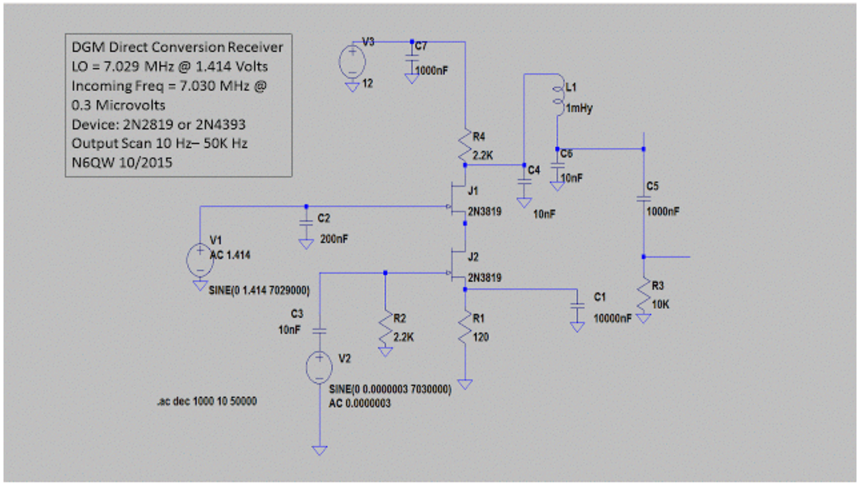
Dual Gate MOSFET Direct Conversion Receiver

Based on inputs I have received either in direct comments on the blog or from email messages, there seems to be a desire to better know the "why" of various choices and actions. In this particular post we will look at the Dual Gate MOSFET being used in a Direct Conversion Receiver (DCR). We will also use an LT Spice simulation to demonstrate the "why".

In the Part 5 we described the Direct Conversion signal frequencies and the resultant outputs. Essentially to receive an 800 Hz CW signal on the 7.030 MHz QRP frequency we would need to supply a local oscillator signal at either 7.0292 MHz or 7.0308. Again the Direct Conversion Receiver is simple to build and is quite sensitive; but does not give single signal reception. You will receive the same signal at TWO places on the dial!

Below is a schematic representation of a Direct Conversion "detector" using JFET's configured as a Dual Gate MOSFET. We have chosen two JFET's for this evaluation and includes the very popular 2N3819 and the 2N4393. The same circuit was used to evaluate both devices and the only difference is the device used in the test bed circuit. The incoming signal has been set at 0.3 Microvolts and the LO is 1.414 volts. The output scan is from 10 Hz to 50 kHz. [Note these photos are GIFs as I was severely criticized by one blog reader for using JPEG's the reasoning for which is still not clear to me but to stop receiving emails --they are GIF's.]

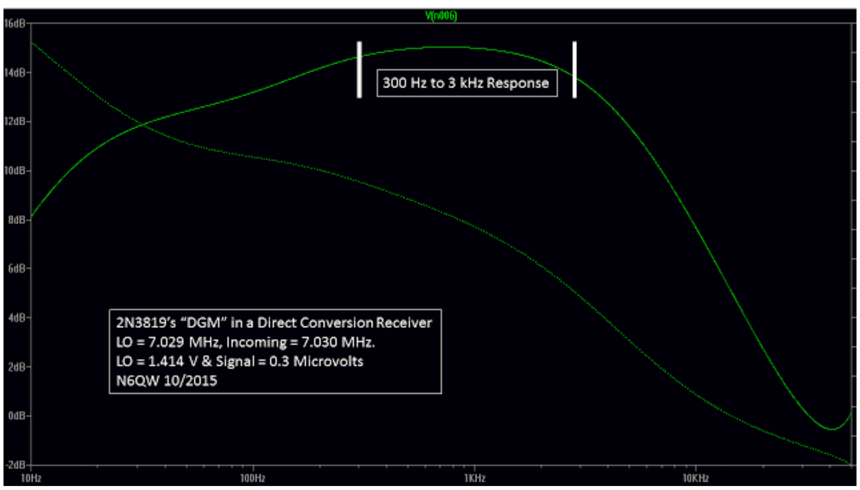
Moved to 20 Meters
Simpleceiver ~ Part 4
Simpleceiver ~ Part 3
Simpleceiver ~ Part 2 Continued
Simpleceiver ~ Part 2
► September (11)
► August (14)
► July (7)

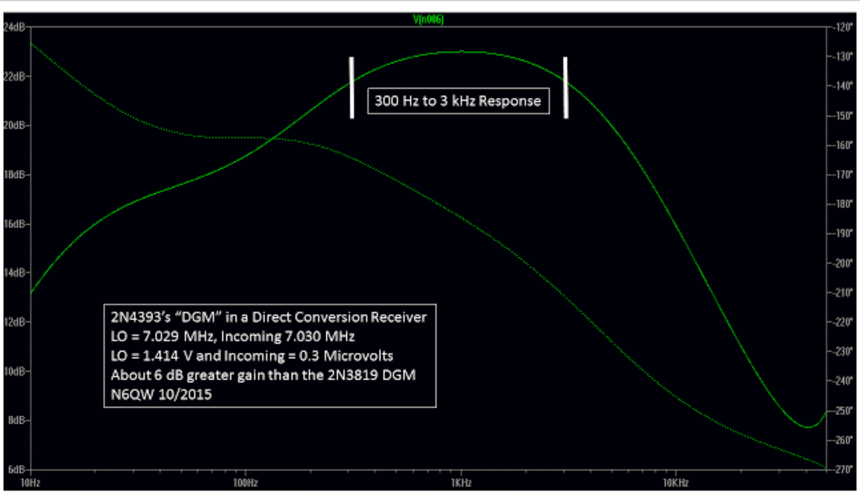


You only need to connect the audio amplifier to this circuit, connect an antenna to "Gate 1" and your favorite Local Oscillator to "Gate 2" and you are in business. Keep in mind the LO signal frequency must be in the same range as the incoming signal.

As homebrewer's the usual process is to dig into the "junque box" and find a couple of devices and heat up the iron AND then wonder why the receiver seems dead. Well this is where my term "noodling" comes into play. Turning on the soldering iron should be the very last step. Evaluating what you are doing and how you are doing it IS the first step!

If you start with the circuit above utilizing the LT Spice simulation you would see below the following expected response. In the first case we use the ever popular 2N3819 and in the second case is the 2N4393. The output curves are very similar BUT the 2N4393 has about a 6dB greater gain than the 2N3819. Will they both work --yes but the 2N4393 is more sensitive to weak signals.





Keep in mind that you need a real antenna to hear signals. Throwing a 10 foot piece of wire on the ground is a compromise (a poor compromise) in comparison to a 40 Meter Dipole at 30 feet. Hooking your Direct Conversion Receiver to a rain gutter may provide some signals but is not as desirable as a real antenna. Put you time and resources into an antenna and then you can remove that as a variable in the reason "why the receiver seems deaf".

Having a signal from a Local Oscillator is one thing but having a signal of one volt or better (1.414 Volts Peak to Peak is 7 dBm) is needed to make this play. Some of the LO devices (AD9850, Si5351) are output frequency sensitive. Thus at lower frequencies there is plenty of output; but at higher frequencies the voltage output drops off and thus may not be sufficient for the mixing process. Thus an outboard amplifier may be needed between the LO and the detector. But unless you measure the output over the frequency ranges you may not realize that insufficient LO drive is causing marginal performance.

In the next post I will have an actual test hardware amplifier that is based on Parts 5 & 6.Stay tuned!

Pete N6QW

Posted by Pete Juliano at 10:07 AM No comments:

Sunday, October 18, 2015

Simpleceiver ~ Part 5

The Product Detector ~ Dual Gate MOSFETS

Plots added for the 2N3819 (10/19/2015)
Data Plots for Additional JFETs Added 10/20/2015

Having covered the audio amplifier stage for the Simpleceiver (again the choice is yours) we will now move on to the Product Detector stage. As the name product detector implies, the output of this stage is a product of the mixing action of two signals.

Think of the product detector as a "black box" where two signals are input to the box and the single output contains two products. One product is the sum of the two input signals and the other contains the difference. Filtering at the output port can remove one of the products.

In its simplest form the "black box" can be the basis of a direct conversion receiver where a variable frequency oscillator (known as a Local Oscillator, LO) is connected to one of the ports and signal from the Antenna (after passing through a stage of RF amplification) is connected to the second port. The sum frequency would contain the LO + Antenna signals but the difference would be in the audio range. Now one of the down sides of the Direct Conversion Receiver is that you get the same audio signal for two values of the LO, where the LO is above AND below the incoming signal. Thus it is not single signal reception. But that does not detract from its capability as a simplistic receiver.

Here is the math part of what is being said. The antenna is tuned to 7.030 MHz and one supplies a LO at 7.0292 and the difference is 800 Hz (nice CW sound). Now if the same 7.030 MHz Antenna signal is mixed with 7.0308 LO signal then the difference is 800 Hz (again a nice CW Sound). In one case the LO signal is above the incoming and in the second case it is below the incoming. BUT it is the same audio signal so you will receive the same signal at two places above the dial. [This also is important in visualizing USB and LSB.] With direct conversion you will receive the same signal at two places on the dial but for a simple receiver this is only a slight inconvenience!

Another example of a product detector response is when a signal is input at 12.0945 MHz (a BFO signal) and the RF signal at 12.096 MHz(coming from a crystal filter) the two outputs would be: 1) 24.1905 MHz (sum) and 2) 1500 Hz (difference). For the product detector, the one we want is the 1500 Hz as this is then the audio output.

Typically we add a low pass filter after the product detector so only the difference (audio signal) is passed. This filter is a Pi type comprised of a 10 NF at either end with a 1 mHy choke in the middle which now will only pass the difference frequencies. Note in this case because the input signal is coming from a Crystal Filter you will have single signal reception which is now governed by the placement of the BFO signal. To receive the opposite sideband you would need a BFO frequency of 12.0975 MHz

Our "black box" can take many forms including 1N4148 diode ring, packaged Double Balanced Mixer's like the SBL-1, Gilbert cells such as the SA602 or SA612, vacuum tubes like the 12AU7, or a Dual Gate MOSFET. Of course the most famous Dual Gate MOSFET is the 40673 which today are on the unobtainable list. Some of these devices have no gain, in fact have a loss while others provide a substantial amount of gain.

Since the Simpleceiver is a minimalist approach we have chosen to use the Dual Gate MOSFET, which is one of the devices that has gain in the conversion process. There are a whole new crop of RF Dual Gate MOSFETs and one in particular is from NXP and is the model BF991. Most of these unfortunately are Surface Mount Devices that for many newbie homebrewer's is an anathema. The Simpleceiver shown in an early post video now has a BF991 installed --so if a homebrewer is not shy about SMD --just drop one of those into the circuit.

Why use the Dual Gate MOSFET?

I would like to take just a few lines to explore the why of our choice to employ the Dual Gate MOSFET in the Simpleceiver given that there are so many new technology "black boxes" at our disposal. Many would say use the SA602 or SA612 which are also gain devices which even have a "twofer" capability wherein you can have the detector and carrier oscillator in a single 8 pin device. Simply plug in a crystal and a few caps between pins 6 and 7 where you have an instant BFO.

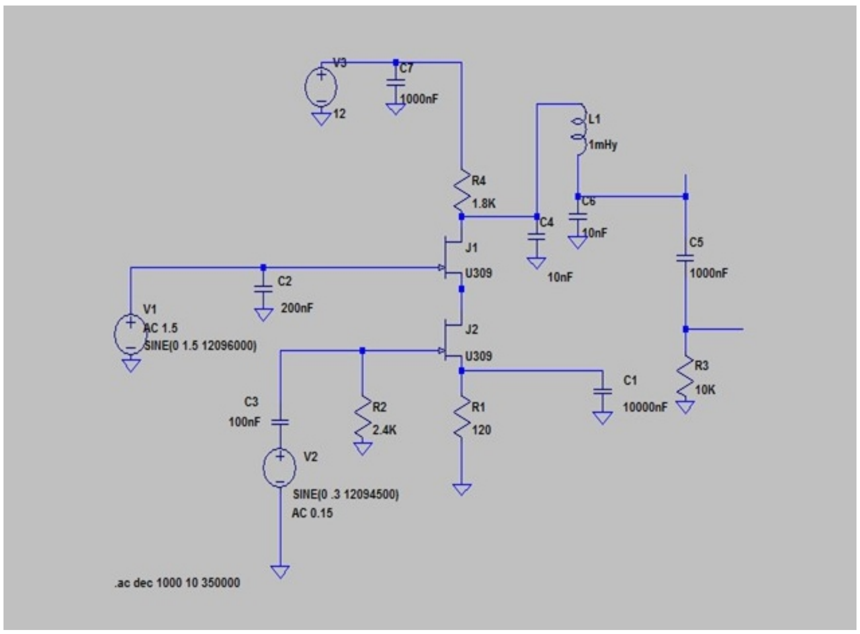
The Dual Gate MOSFET is not a black box like the Sa602 or SA612. As my friend Bill, N2CQR would say about a DGM, "you can better visualize the signals being applied to the device and have greater in depth understanding of the signal conversion process." This also satisfies his term of "more homebrewedness" with discrete components.

But the SA602 or SA612 can be used equally as well with the choice is left to the builder. BUT we do have as a goal for the completer Trans-receiver project to use the Dual Gate MOSFET in many of the circuits and given we bought them for 20 cents a piece (delivered) that is far less expensive than the Gilbert Cell SA602's/SA612's which cost about $3 USD --each!

At this point I will leave it to the reader to further explore the pros and cons of the Dual Gate MOSFET (DGM). Some will argue noise figure issues, while others will argue tendency to overload and lest I forget phase noise issues. There are always better mousetraps; but on the continuum of choices, for a simple project, the DGM passes muster as a viable candidate.

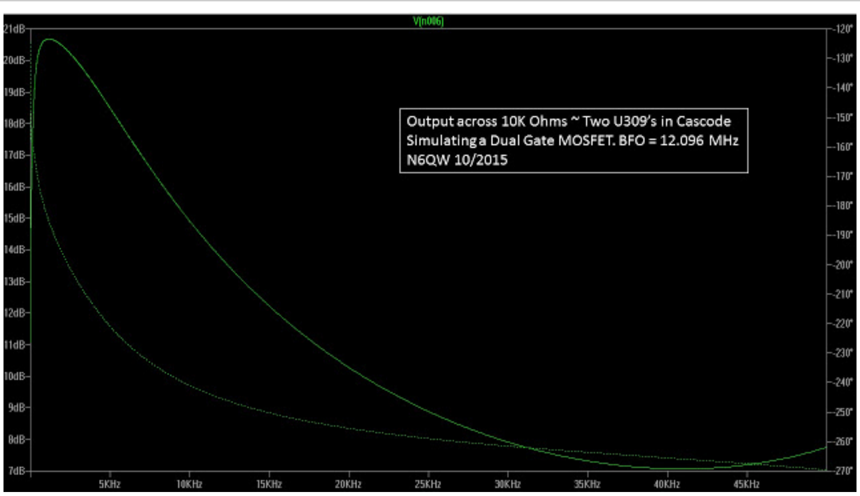
But realizing that those new to homebrewing do not have 50 years experience soldering their fingers together on a routine basis, we offer the alternative of making a Dual Gate MOSFET from two individual leaded type J310 JFET's. These devices are plentiful and recently a 50 piece quantity J310's was purchased with shipping for around $10 USD.

In one of the earlier posts we mentioned the use of LT Spice to simulate the circuit that will be used in the Simpleceiver and so it is with our "homebrewed" DGM. Initially I missed the selection for JFETS and used MOSFETS. You certainly can get some interesting results using two IRF510's in Cascode (***Source*** of one device connected to the ***Drain*** of the second device -- Read up on Cascode circuits using a Google search). Actually I think it will work -- but a better choice is the U309 which is close to the J310. The 2N3819 resulted in less gain for the same set of circuit values. So below is my simulated DGM using two JFET's in a Cascode Circuit. In the audio range -- the simulation shows about a 19 to 20 dB of gain.



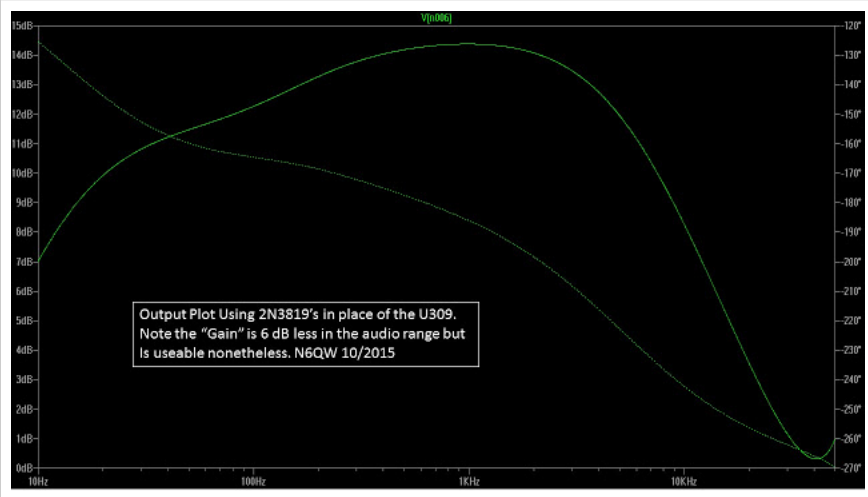
This is the circuit that was simulated for our homebrew DGM (U309's in Cascode) and below is the output plot. This works!! In our next post (or an addendum) we will build the circuit and mate it up with the audio amplifier stage. Stay tuned.

73's
Pete N6QW



In this post we mentioned that for the same circuit the use of the 2N3819 had less gain for the same set of circuit values. It is about 6 dB less and the plot for that is shown below. Do we now rise up like those who bash the Si5351 phase noise claiming that it is 6 dB

worse than the Si570. NO is the answer! The 2N3819 is a viable device --it just has less gain. This is the value of LT Spice --no soldering is involved in the evaluation and we now can expect less gain with the 2N3819. Our frequencies of choice between 300 Hz and 3 kHz for the 2N3819 vary by only about 1.5 dB.

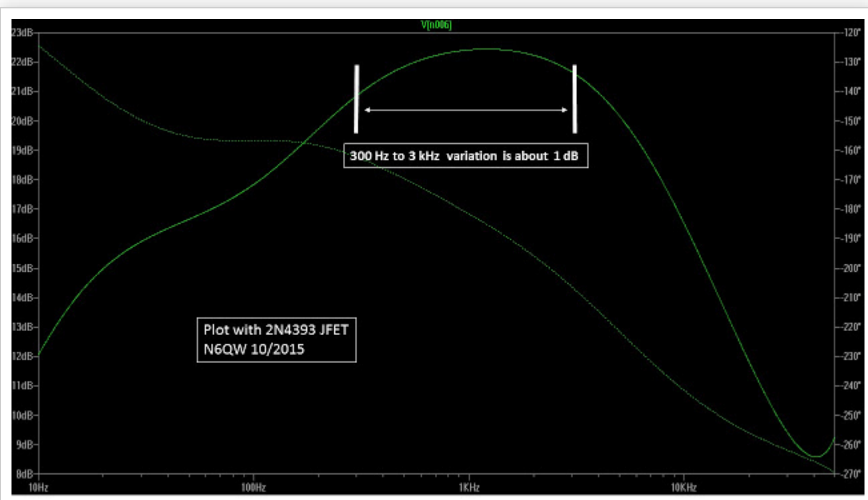


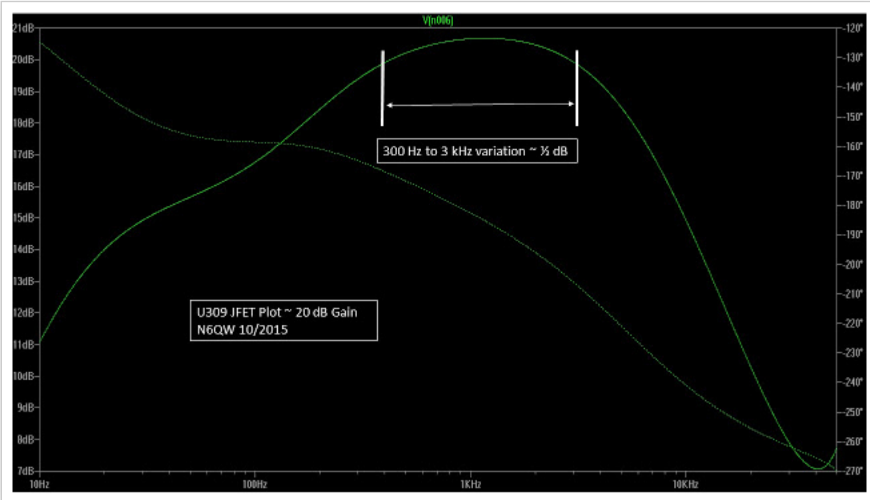
10/20/2015

The added value of the LT Spice simulation aside from assuring that a device will work in the circuit is the cost factor. The U309 is about $6 USD (remember we are using the J310 which is 20 cents) and another good candidate is the 2N4393 which is about 1/3 the cost. So how would these stack up in an apples to apples comparison. I re-ran the plots for these two devices and the results are shown below. The striking difference is about 1/2 of a dB (your ears will never know) improvement at 3X the cost. Gain variation as well as ***maximum gain*** must also be considered and the 2N4393 has slightly better overall gain than the U309 in this circuit. So this makes it an easy choice to go with the 2N4393 for this application.

The 2N3819 would be "Good Enough" but has about 6 dB less gain. The J310 is less expensive and when used in this circuit works better. I am trying to locate the data factors for the J310 so I can run this same plot. What I have now is practical data of how the J310 works versus the 2N3819 -- but for some who read this blog -- that is not good enough. [Usually I get an email that someone read on the EMRFD or BITX reflector that the J310 was not a good device yet they have no practical experience with the specific device!]

Pete N6QW





Posted by Pete Juliano at 11:14 AM 6 comments:

Friday, October 16, 2015

Belthorn (Bell Thorn) III Moved to 20 Meters

Belthorn III Moved to 20 Meters and Making QRP Contacts!

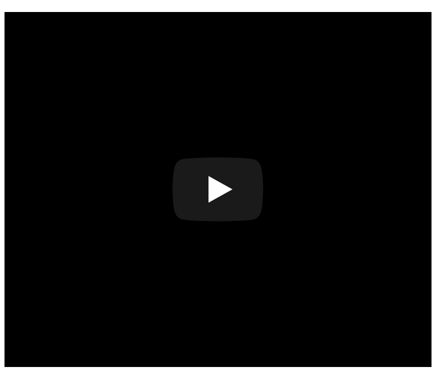
Several months ago I resurrected a project that was built some 12 years ago and updated the rig with a Si5351 + Arduino Controller, a color display and a new box. This radio had some innovations like using a Motorola Gain Block amplifier (CA2818C) which happens to be a 24 VDC device and led to embedding a DC to DC Convertor (MeanWell) into the project. It is a single conversion at 9.0 MHz and uses a GQRP Crystal Filter. The Arduino sketch includes a built in tone oscillator to provide a 988 Hz tone for tune up purposes.

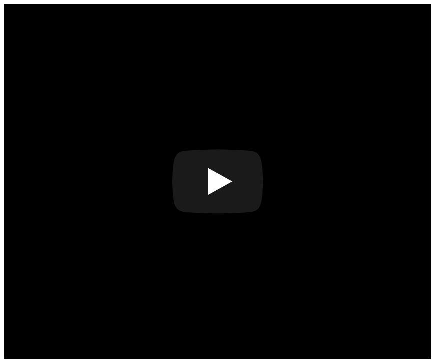
The RF AMP is an IRF510 but I wished I had used a real RF Transistor like a 2SC3133 as the output on 20 Meter is slightly less than on 40 Meters. I am seeing about 7 watts on 20 Meters where I got close to 10 Watts on 40 Meters.

Now that I have a new beam antenna I decided to move the Belthorn III to 20 Meters and one of the first QRP contacts was with N0TUX/KH6. Thanks to Ron Taylor G4GXO for the original Belthorn design. Thanks Ron -- the Belthorn still perking along after 12 years!

There are two videos and the second is of the QRP contact. Check http://www.n6qw.com/ for more info on the Belthorn III.

73's
Pete N6QW





Posted by Pete Juliano at 9:49 AM 1 comment:

Sunday, October 11, 2015

Simpleceiver ~ Part 4

Audio Amplifier Stage

Addendum 10/13: You Tube Video of a Test Amp.

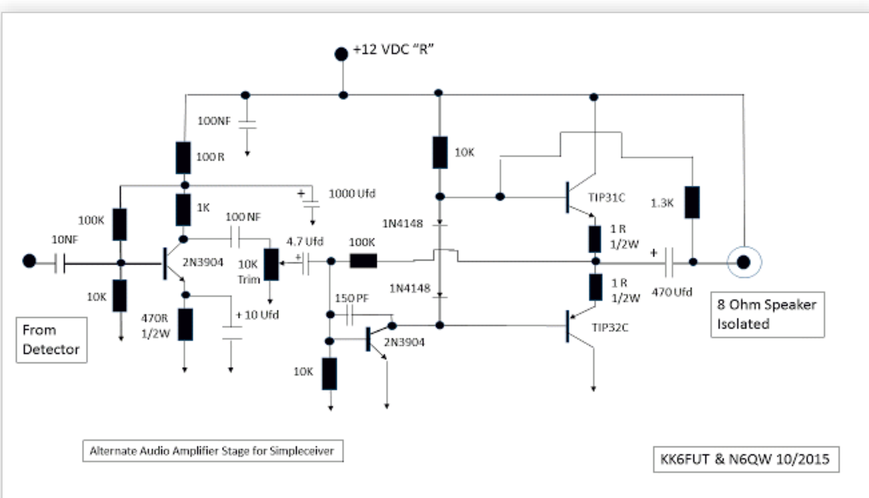
In our last posting we gave some advice about starting from the back end and working your way forward through the build. Not only does this chunk the project into manageable pieces but also enables test as you go. Thus the completed assemblies in effect become part of the test system. You may argue with that approach; but it is a sound practice. Somehow soldering all of the project parts to a circuit board and hoping it works is only asking for trouble!

We received an input in our last post about the LM386 audio amp IC and the issue of distortion when run at 200X gain. At this point it is uncertain that this excellent input, by the way, is based upon an individuals experience or just information floating around reflectors. But we did want to further explore the input and to give our response and take on the subject.

By design the Simpleceiver is just that --a project with minimum part count and easy to replicate. The audio amp stage is what I call "Good Enough" to get you started and is a totally viable circuit. That brings up the other aspect of the Simpleceiver and that is the circuit block module approach. Once the radio is built the homebrewer is encouraged to test new circuits and devices.

Thus the Simpleceiver ***IS*** an experimenter's platform. So if a builder finds the LM386 an objectionable device then by all means substitute your favorite circuit or one that has been approved by some reflector like the BITX or EMRFD groups. The LM386 can easily be changed to an LM380 (8 pin or 14 pin version) which of course can put out as much as 2+ watts. You can also try the TDA7052 -- like I said I smoked six of those in the recommended circuit. Or you can use just the pre-amp stage (2N3904) and feed an external audiophile style amplifier. The important thing to note is experiment and adjudge for your self.

For those who would like to build a discrete version of an amplifier a circuit is presented below. It is the same pre-amp stage followed by a complementary amp stage (straight from the Internet). I do know that several hams have tried simulating the complementary circuit in LT Spice and were unsuccessful -- I am no help there --other than I have built and it works. While it has more Pout than the LM386 I would say it is on par with the LM386 insofar as perceived or real audio distortion. You will note --lots more parts and the need for an isolated output.

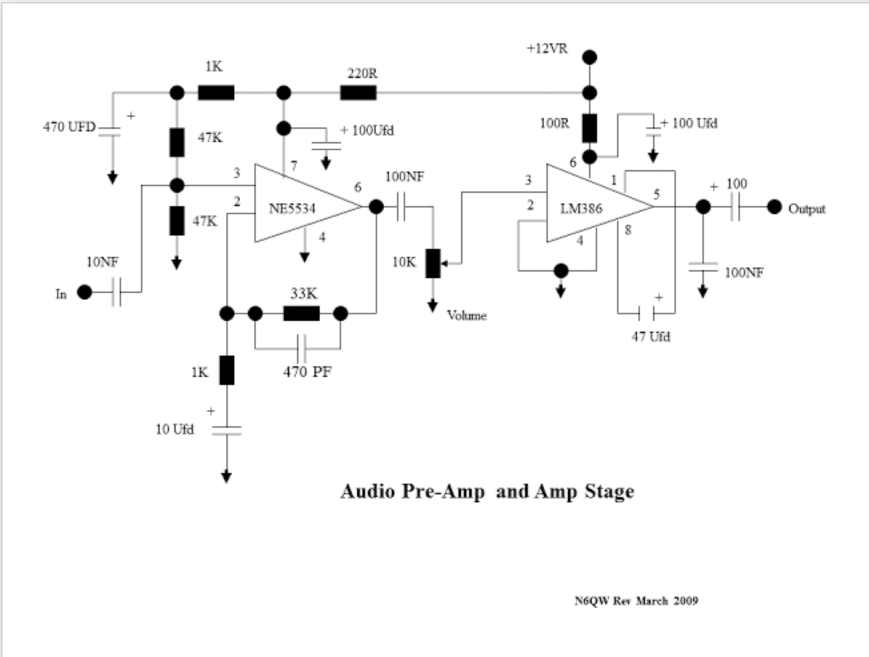


Discrete component audio amplifier stage

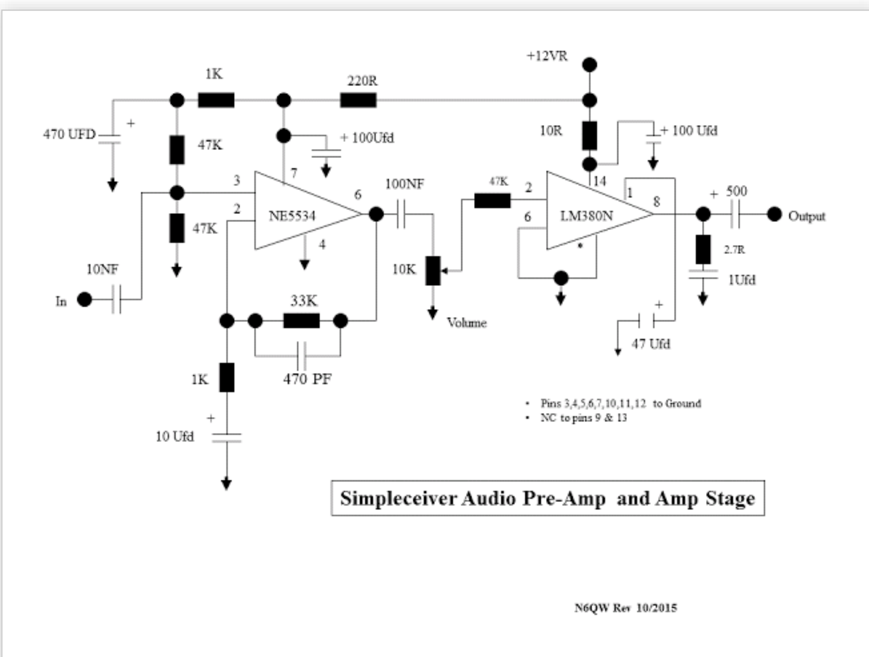
In the spirit of providing alternatives for the audio amplifier for those still skeptical about the use of the LM386 then we offer the following additional circuits. These have been built and used in several radios at N6QW. But I keep coming back to "simple and good enough".

The first uses an op-amp as the preamp and the device of choice is a low noise version of the NE5534 followed by the LM386 (Oh oh here we go again about distortion at high gain.). This audio amp circuit was used in my 2009 Tri-Band Solid State version of the Heathkit HW-100. You can see this as one of the links at http://www.n6qw.com/

The only reason this is being shown is to demonstrate how this circuit was later converted to use the LM380N. Important point again about experimentation and circuit improvement. In this case the real improvement with the LM380N -- 2+ watts Pout.



The next schematic is the same circuit as used in the KWM-4 transceiver project in 2012 and the changes involved replacing the LM386 with the LM380N. Known for its greater output power it also has less distortion than the LM386. In passing take a look at the specification sheet for the LM380N and the "innards circuit schematic" is not unlike the discrete component amplifier shown at the beginning of this post. Hmmm there is a story here.

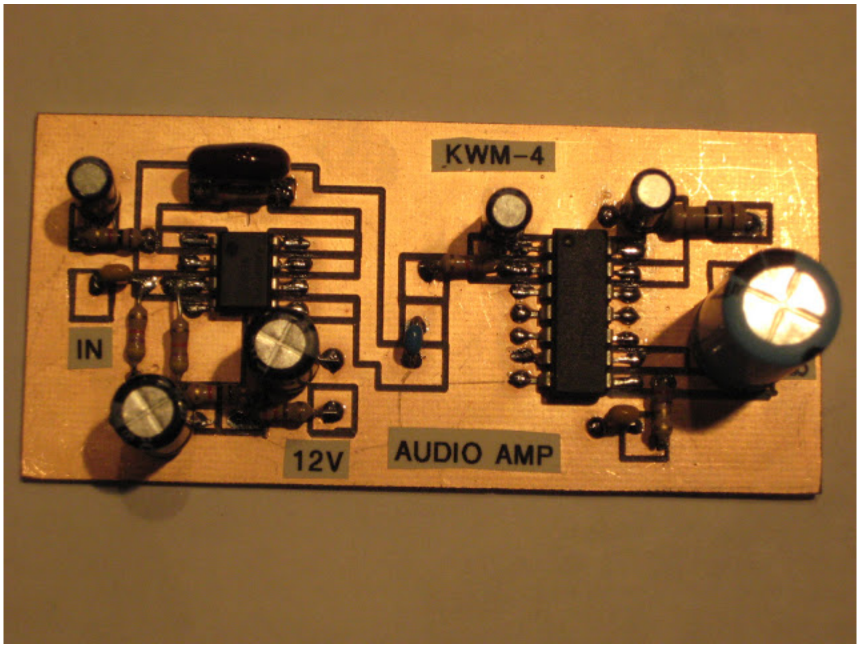


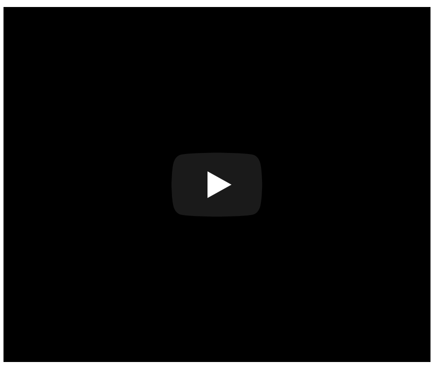
Below is a photo of the LM380N amplifier as used in the KWM-4 transceiver project. There are island blocks in the center of the board and this is where the 10K audio gain pot connects. (I am just heading off any questions that there doesn't appear to be any connections to some of the blocks. Having a CNC mill sure makes it easy to crank out prototype boards like this.)

To recap the audio amp stage should be the first item built and get working! We have presented options and hopefully have addressed the input about distortion in the LM-386. My take it is good enough and if you find it objectionable then you have the option of even taking the 2N3904 pre-amp stage and fitting that to the LM380N. It is all about experimentation!

Please note that unless you solder the ground pins of the LM380 directly to the circuit board and have good contact with the body of the LM-380 to the copper board you will need to add a heat sink to the LM380. (Such as the case should you use a DIP socket.)

73's
Pete N6QW





Posted by Pete Juliano at 9:14 AM 8 comments:

Thursday, October 8, 2015

Simpleceiver ~ Part 3

Secrets of Homebrewing Revealed

How to build a project

Heathkit had it right and much to their credit they had a very high success rate with their kit projects. Let us examine the difference between the Heathkit approach and today's kits. Much thought went into a Heathkit project so that there was a logical and progressive build concept that frequently is missing in today's kits.

Typically a kit today, as received, is a bag of parts with an internet address and perhaps an link to a you tube video. Ben KK6FUT has called this solder smoke --you ***solder*** all of the parts and then watch it ***smoke*** when power is applied. The Heathkit approach was to chunk the overall build into logical and manageable small sized tasks and to test as you go. In effect the portions of completed work enable the builder to verify a circuit is working before proceeding to the next phase. In essence the portions completed become a part of the overall test system. We strongly believe in this approach and Ben and I in the many articles we co-authored have adopted that principle.

A friend in the UK Nick (G8INE) sent in the following which adds a bit to the decode about today's kits and kits building practices.

- ***A lot of kits arrive as either a single bag of bits, or the components divided by type, not section so there's a tendency to press on once the bag is open.***

- ***The received knowledge in many instances is to build from the lowest components up, its easy to start putting ALL the Rs in, then ALL the Cs, and that is encouraged in many places.***
- ***Some "kit" building starts with the bare board, and then building once you get all the parts – it needs a lot of self-discipline to break that sort of build up into testable stages, especially as by the time that you get to being confident working that way, one tends to be confident that it'll work, or that you'll be able to debug it …***
- ***The whole kit building culture has shrunk, so the pool of wisdom extolling the virtues of a staged approach isn't there as a part of the landscape, just Pete and Ben shouting the message !!***
- ***There's a sort of instant gratification culture where people don't expect to embark on long projects anymore, so the expectation is that you can just settle down and blast through the process in a single sitting.***
- ***There's a lack of building culture, so people tend not to have all the right tools which includes patience and the attitude that encourages you sit and look at what you're doing then think it through as well as the hard tools.***

[Thanks Nick --many really excellent points about the why of today. Pete N6QW]

Another piece to the puzzle is something Bill, N2CQR and I frequently hear arising from the SolderSmoke podcast is: "How do I know something is working?" We are frequently amazed that many new to homebrewing just don't know. By chunking circuit elements into small pieces this enables the homebrewer to really delve into each circuit element and to understand what is occurring in that part of the circuit. No collector voltage is a sure sign of two things: 1) the circuit is wired improperly and 2) no collector voltage, it follows no output. Pretty simple but often overlooked.

In the LBS* project a person emailed me with a photo of the audio amp circuit he built from the project and had included voltage measurements. The subject of the email was of course "Your Circuit Doesn't Work!" At one point the measurement was 3.0 Volts and another point it was "0" volts and yet these two points were supposed to be connected. Thus both should read either 3.0 Volts or "0" volts. Close inspection of the photo showed the points were ***not*** connected. The individual had the answer in hand but never looked at the why of the data. Connecting the points made the circuit perform as it should. Homebrewing is more than ***Solder and Smoke***. Now if this person forged ahead simply built the whole radio and had the same result (no audio) where do you start looking for the problem?

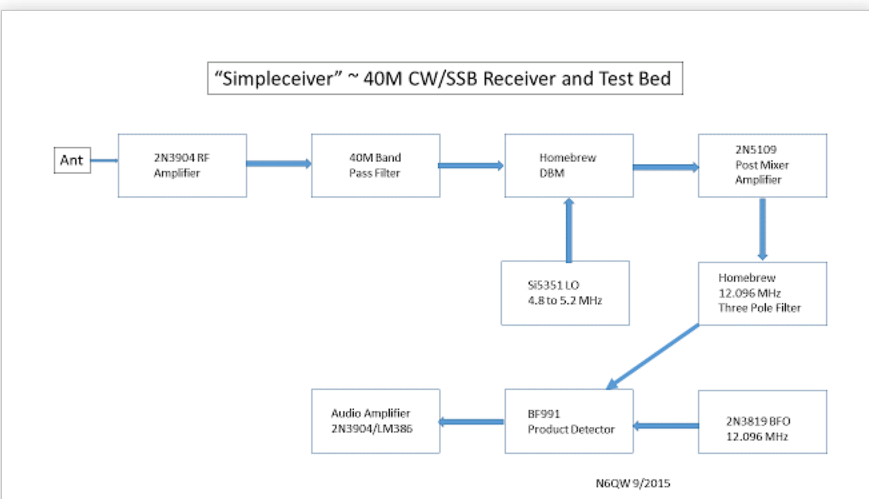
Where to Start?

The first step is to start from the back end and work forward. Below is the block diagram of the Simpleceiver. This is slightly different than the original post as the audio amplifier has been changed to a 2N3904 driving an LM386. Appropriately this is the back end and ***the*** starting place. Build the audio amp and get that working. A simple go no go test after making sure of the following is to simply connect power (see caution) and a speaker. Then placing your finger on the input should result in a large hum from the speaker --you ***will*** know if it is working. If there is no output then you will only have to deal with a small portion of the overall project to find out the why.

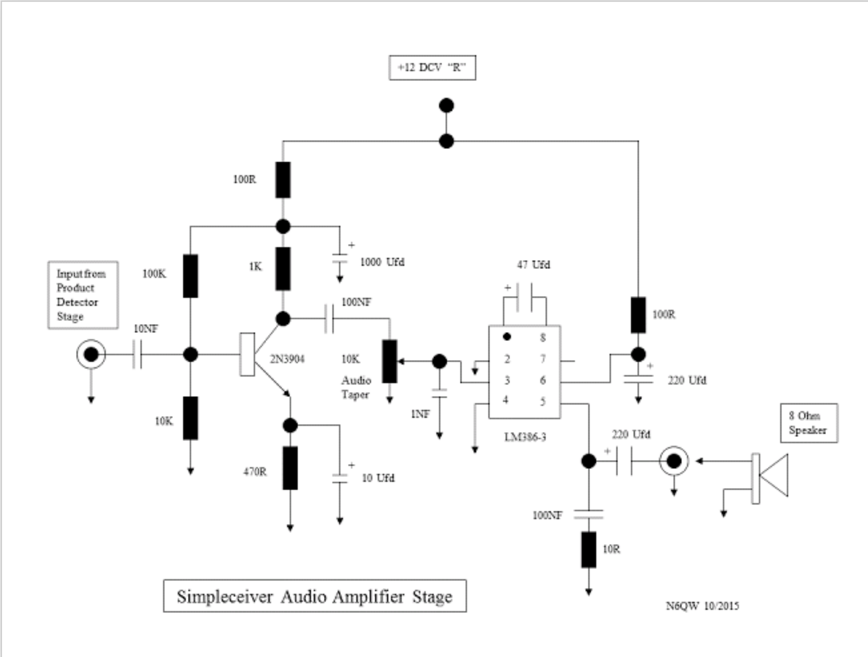
Steps before "Power On"

1. Check all wiring to insure the wiring matches the schematics.
2. Look for poor solder (cold) solder joints --this is soldering not welding!
3. Look for any shorts or solder bridges.
4. Insure all parts are the parts to be installed
5. Insure that transistors and diodes have been installed with the correct polarity.
6. Install a 1N4002 in the Plus power lead with the arrow pointing toward the circuit. (This prevents the circuit from going up in smoke when you hook up the power leads backwards.)
7. Avoid the use of Wall Warts!

Once you have gone through this list apply power and hope there is no smoke.



Simpleceiver Audio Amplifier Schematic Diagram



This is the schematic that will be used for the receiver. In an earlier post we mentioned that the free simulation software was a handy tool. The 2N3904 pre-amp stage was simulated in LT Spice and the addition of the 1000 Ufd bypass cap was a result of that simulation. In case you are wondering this circuit has been used and reused many times in our projects. It works --so keep things simple and just use it!

* LBS s shorthand for Let's Build Something which was a two part article in the January and April 2015 Issues of QRP Quarterly co-authored by Ben, KK6FUT and Pete, N6QW. This project started with a direct conversion receiver and by utilizing most of the block modules from the direct conversion receiver ended up with a 40 Meter SSB transceiver. The Simpleceiver and companion Simpleciter is like the LBS in that it ends up being a working transceiver but uses a different approach.

73's
Pete N6QW

Posted by Pete Juliano at 6:22 AM 7 comments:

Monday, October 5, 2015

Simpleceiver ~ Part 2 Continued

The Art of Homebrewing --- Continued

In our previous post we outlined some "homebrewing get ready" actions such as setting up a filing systems and securing certain publications. We now want to continue that journey.

The Hardware Part of Homebrewing

- Homebrewing tools and equipment can make or break project and so often even basic test instruments have not been secured and the question I frequently get "How do I know it is working?" You will only know if it is working is by testing and if it is not working then a troubleshooting procedure needs to be in place.
- Basic tools include a good quality pair of needle nose pliers, wire cutters (nipper), screwdrivers (various sizes of flat head and Phillips), a small adjustable wrench, flashlight, and exacto knife. Add to that a pair of forceps and tweezers. Also don't forget a suitable workspace with good lighting and last but not least a temperature controlled grounded soldering iron.
- Test equipment is a must! Some can actually be homebrewed and works just as well as commercial units. A Digital Voltmeter (DVM) is a basic item of equipment needed in the shack. There are all kinds and varieties and some have functions beyond measuring resistance, voltage and current. Some will check transistors and diodes, while others can also measure frequency, as well as inductance and capacitance. Another tool which used in conjunction with the DVM is an RF probe which contains only 3 parts and thus easily homebrewed. An SWR bridge is another handy tool for checking RF output. Don't forget the dummy load which can be made from twenty 1K Ohm 2 watt non-inductive resistors which are connected in parallel. Effectively you have a 50 Ohm, 40 watt non-inductive resistor "dummy load" which is perfect for testing QRP transmitters.

- Moving on to more sophisticated test equipment entails being able to see and accurately measure your signals. The two most frequently used items are an Oscilloscope and Frequency Counter. Many of the current crop of Digital Storage Oscilloscopes have a built in counter so it is a two for one. In the interim and in lieu of an oscilloscope (you will eventually need one of these) and frequency counter (you eventually will also need one of these) a General Coverage receiver with a BFO becomes a critical piece of test equipment. Many of these can be found in the $50 range. use of such a receiver enables listening to say an oscillator (verifying it works) and secondly it will tell fairly accurately the frequency of oscillation --it is a two for one test.
- A "Junque Box" is one of the most critical pieces of the Homebrewing Art and having the right parts at the right time enables rapid prototyping as well as saving money. In time the seasoned homebrewer will find that buying a single part costing 15 cents often results in a shipping charge of $6.50 USD. But you can buy 100 parts for the same shipping cost. There is a message here and that is "buy in bulk". Most circuits we use tend to have common resistance and capacitance values (such as 100 Ohms, 1 K Ohm, 10 K Ohm, 10 NF, 100 NF, 10 Ufd, 100 Ufd) buying these in bulk is a good start. The same for solid state devices such as 2N3904, 2N3906, LM386, etc. The Simpleceiver will use JFETS (J310) and I recently purchased a 50 piece quantity for 16 cents each and with shipping was less than $10 USD --that is 20 cents a piece delivered in my hand. One of the auction sites recently had a listing of 1200 pieces (20 pieces each of 60 resistance values) of 1% resistors for $6 USD. True it will take 3 weeks for shipping but at that price -- 1/2 cent each --it is worth the wait. Ferrite cores such as the FT 37-43 are used virtually everywhere from homebrew double balanced mixers to RF chokes. The Toroid King has amazing bargains on these cores. Diodes such as the 1N4148 bought in bulk can be had for 'pennies a piece" and these are used literally everywhere from homebrew double balanced mixers to "snubbers" on relay coils as well as their intended use in diode switching.
- Enough of the boring but vitally necessary stuff and I will end here. 73's Pete N6QW

Posted by Pete Juliano at 5:57 AM No comments:

Thursday, October 1, 2015

Simpleceiver ~ Part 2

The Art of Homebrewing, A Disciplined Process!

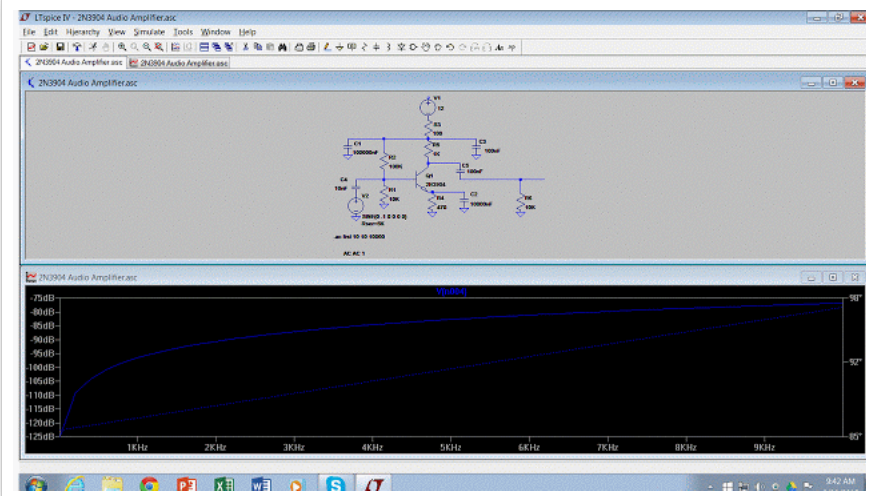
Addendum 10/2/2015~ Schematic

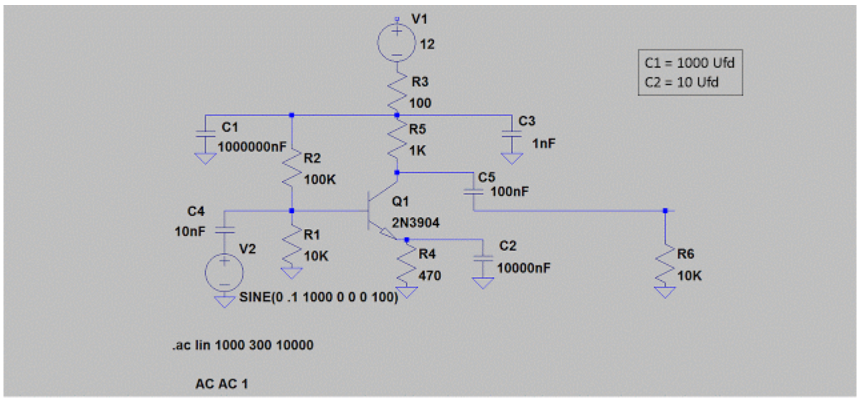
Having spent most of my working life in the aerospace industry I can tell you first hand that having disciplined processes is paramount to producing high reliability products. It is only through disciplined processes that one can achieve consistent outcomes. That same logic applies to our wonderful hobby. Randomly tack soldering a bunch of parts and wires could be successful but that most likely is a rare exception rather than a consistent outcome. Thus having a disciplined process for approaching homebrewing will move you way up the success curve.

The very minute someone mentions a process there are all sorts or rigorous rules that are envisioned and that not is not what is meant. A disciplined process in our context is more so an organizing effort that enables doing tasks in a logical, sequential and measured manner. We are lucky for today with just a few mouse clicks we have much of the information needed to build our disciplined process and be successful at homebrewing a radio project.

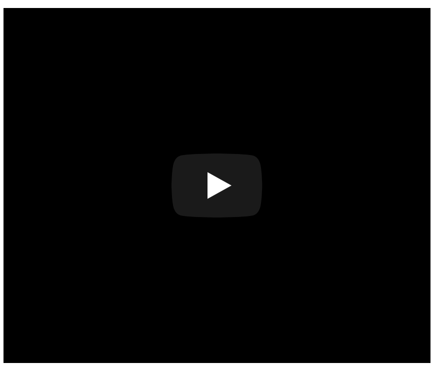
Every process must start with two critical pieces of information: where to start and the desired end state. This may sound simplistic but often the failure to accurately identify these two pieces results in a major disaster. Starting by turning on the soldering iron and 'welding" parts together says it all. You will often hear me repeat lighting up the iron is one of the last steps in the process.

- Deciding on what project is a really good starting point --and start with a small project. The Michigan Mighty Mite, 80 Meter CW transmitter is a great example. About 12 parts including the Low Pass Filter and the level of complexity is ideal for a first project. One creative ham lacking the tuning capacitor built his very own cylindrical capacitor from two beer cans and some electrical tape. So don't overlook the possibility of homebrewing all of the parts. Another might be building a simple dipole antenna. Or maybe a crystal set. But don't light up the iron yet --- there is much more to do.
- Information gathering is the next step. Simply downloading a bunch of information on to your computer, tablet or Smart Phone without a thought about how to organize the data is a huge mistake. In the future you will want to retrieve the data you collected and having a process to store and retrieve data is key. I have several file folders on my computer where I organize my data. These include: Specification Sheets (pin out data, power ratings for various devices, etc.), Receiver Projects, Transmitter Projects, Transceiver Projects, Design/Technical Notes, Antenna Projects and Software.
- Start by "Googling" Michigan Mighty Mite and do a similar search of You Tube. You will be absolutely amazed at how much information exists on this project. Do overlook the SolderSmoke Blog and other blogs that are searchable. Save the information in the appropriate folder.
- Find, beg, borrow or steal the following publications: Solid State Design for the Radio Amateur (Hayward), W1FB Design Notebook (DeMaw), QRP Power (ARRL). You can bypass the ARRL Handbook and EMRFD and this is just a personal opinion. While these two publications are good in their own right, the ones suggested are more practical in nature and written for those just starting out. There are two quarterly publications that are useful: QRP Quarterly from QRPARCI and the SPRAT from the GQRP club. I am more inclined toward these magazines more so than QST because of my bent on homebrewing. If you wanted to read about the zillion radio contests or see a review on the latest $12000 radio then by all means jump to QST. In particular two of recommended publications (Solid State Design and W1FB Design Notebook) form the basis of much of the background circuits that are used in the Simpleceiver.
- Download and install the following free software. EZNEC for antenna modeling, LT SPICE for circuit simulation and Arduino IDE (you will need this later). We have a favorite single transistor amplifier circuit that has been used as an audio preamp and as a microphone amplifier. We have simulated that circuit using LT Spice and are presenting that below. Mouse clicks and no soldering irons were used to evaluate the circuit properties. This is the real power of the software as it lets you run various cases so that you can optimize the performance. I found a "notch" in the output and this was fixed by adding a larger size bypass capacitor.





Amplifier Under Test ~ LT SPICE. N6QW 10/2015



The simulation software not only gives you a quick look at circuit performance but also enables a bit of tinkering to perhaps stretch the Frequency Response or increase the Power Output. Mouse clicks not soldering irons (at least at this stage) is the order of the day.

Stay tuned for more information on the Art of Homebrewing Process.

73's
Pete N6QW

Posted by Pete Juliano at 9:00 AM No comments:

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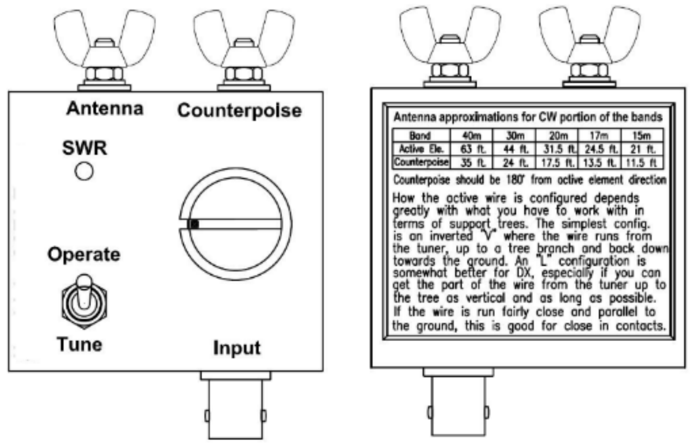
Pacific Antenna 80m SOTA Tuner



First, familiarize yourself with the parts and inventory the kit using the table below.

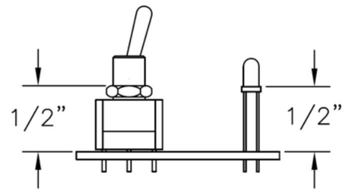
Parts List

Inventory	Component	Quantity	Note
	SWR Indicator Kit	1	SWR Bridge Kit
	T94.2 toroid	1	Large red toroid core
	Polyvaricon	1	Variable Capacitor
	Polyvaricon shaft screw	1	2.6 x 12mm Phillips pan head screw
	Polyvaricon mounting screw	2	2.5 x 4mm screw
	Washers for mounting screws	2	Lockwashers for polyvaricon mounting screws
	Polyvaricon shaft	1	3/8” white Nylon standoff
	6-32 screw	2	3/4” Stainless phillips pan head screw
	#6 lock washer	2	Stainless
	#6 flat washer	2	Stainless
	6-32 wingnut	2	Stainless
	#6 nylon step washer	2	Nylon, white
	#8 nylon flat washer	2	Nylon, white
	#6 tinned solder lug	2	Solder Lug
	6-32 nut	2	Stainless
	4-40 screw	2	1/4” Undercut flat head
	BNC	1	Female, chassis mount
	1/4" shaft knob	1	Black plastic knob
	Magnet wire	72”	Red or Green #26 wire, 72 inches long
	Hook-up wire	18”	#22 or # 24 AWG, two colors, 9” each
	SOTA chassis	1	Aluminum, unfinished
	SOTA decal set	1	Waterslide decal sheet

Assemble the SWR Indicator Kit.

Complete assembly instructions for the SWR indicator kit are located on-line at http://www.qrpkits.com/swrindicator.html .

The last component to solder to the SWR board is the LED. Use the above dimensions to locate the lip of the LED.



Adjust the inside nut of the switch, for the correct fit to the chassis so that the LED will just fit through the case when the SWR indicator is installed.

Set the SWR indicator aside, for now as the rest of the assembly is done inside the chassis.

Prepare the chassis

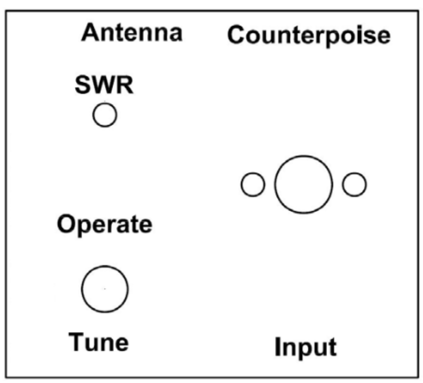
Thoroughly clean the surface of the panel to remove any oils or contamination.

TIP: We have found that moving the decals into position on a bare aluminum chassis is sometimes difficult, due to the brushed surface, so we recommend either painting or pre-coating the chassis with Krylon clear, or a similar clear coating, and allowing the coating to thoroughly dry before applying the decals.

Decal Application

The supplied decals are known as water slide decals. An example video of how to apply these types of decals can be found here: https://www.youtube.com/watch?v=Pr5R9VCNVHU

It is recommended to apply the decals before mounting anything to the chassis.



Use the above picture as a guide for the correct spacing of decals around the holes to prevent any labels being covered by a knob or switch.

Cut out and trim around each group of text or symbols you wish to apply. Trimming doesn’t have to be perfect as the background film is transparent.

After trimming, place the decal in a bowl of lukewarm water with a small drop of dish soap to reduce the surface tension for 10-15 seconds.

Using tweezers, and carefully handle decals to avoid tearing. Start to slide the decal off to the side of the backing paper, and place the unsupported edge of the decal close to the final location.

Hold the edge of the decal against the panel, with your finger, and slide the paper out from under the decal. You can slide the decal around to the right position, as it will float slightly on the film of water.
You may find it helpful to use a knife point or something sharp to do this.

When in position, hold the edge of the decal with your finger and gently squeegee excess water out from under the decal with a tissue or paper towel.

Working from the center, remove any bubbles by blotting or wiping gently to the sides. Take your time and do this for each decal.

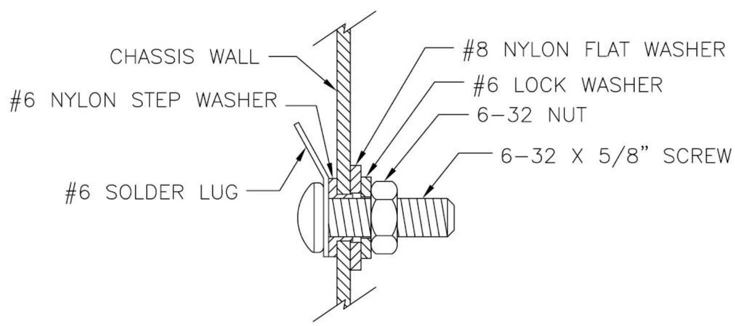
Let the decals to dry overnight, and you can speed up this process by placing the chassis near a fan.

When completely dry, the decals should be sealed and protected by spraying at least two light coats of a clear matte finish, such as Krylon, or other similar products to. It is important to apply only light coats and to allow each coat to completely dry between applications

Once the final clear coat has dried thoroughly, continue as follows:

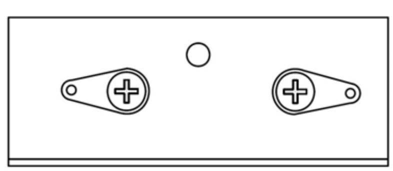
Install the connectors and hardware on chassis

Assemble the two antenna connections and the bnc connector to the chassis cover.

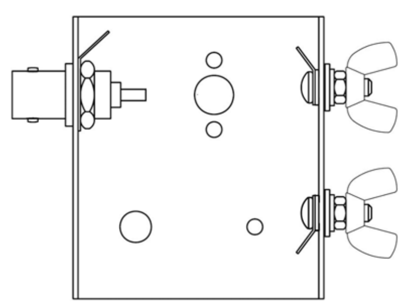


NOTE: The nylon step washers are used to keep the antenna connections insulated from the chassis.

Position the solder tabs as shown below, and angled down slightly, so that the antenna lug does not short against the PEM nut when the case is assembled.

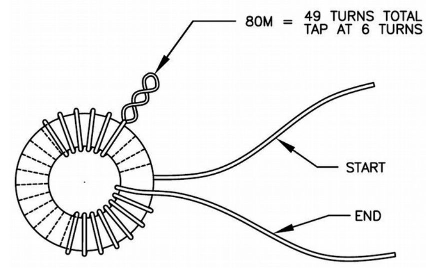


AS VIEWED FROM THE INSIDE



Check that there is no continuity between the solder tabs and the case at this point. This is to verify that the insulating washers were installed correctly.

Wind L1

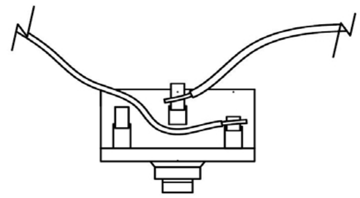


Use the T94-2 large red toroid and the enclosed magnet wire.

When complete, L1 will have a total of 49 turns, with a tap at 6 turns from the “START” end.

Remember, every time the wire passes through the center of the toroid, counts as one turn.

Pre-wire the Poly-varicon



Wire as shown with 2” pieces of the hook-up wire, to the side shown.

Note that we are only using the 150pF side for 80m.

At this time, adjust the small trimmers on the back of the poly-varicon for half engagement.

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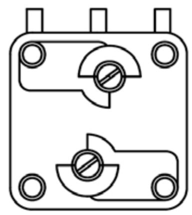
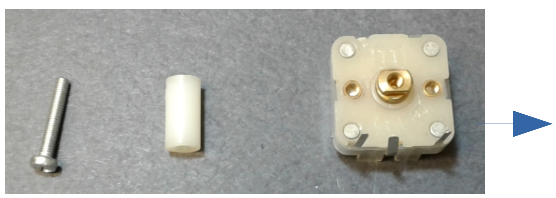
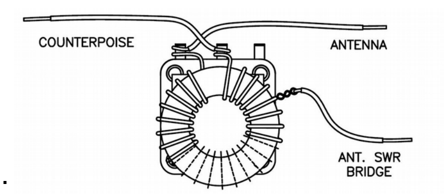


Mount the shaft and center screw provided on the polyvaricon



Cover the back of the poly-varicon with electrical tape. This will act as a surface to secure the toroid.



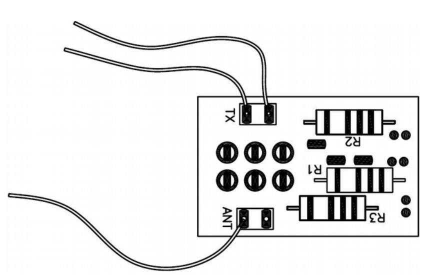
Wire the toroid to the poly-varicon as shown, and solder three pieces of 2” long hook-up wire as shown.

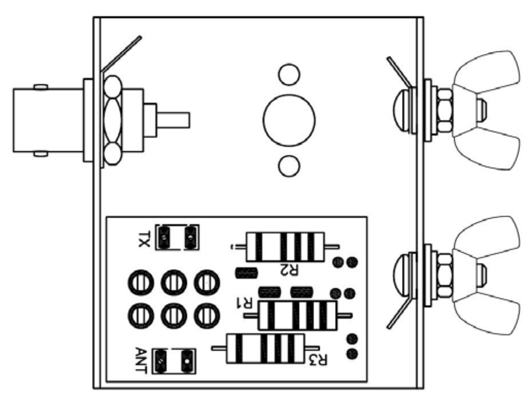
We will secure the toroid later with a couple of drops of hotmelt glue or adhesive.
Mount the poly-varicon shaft with the screw provided

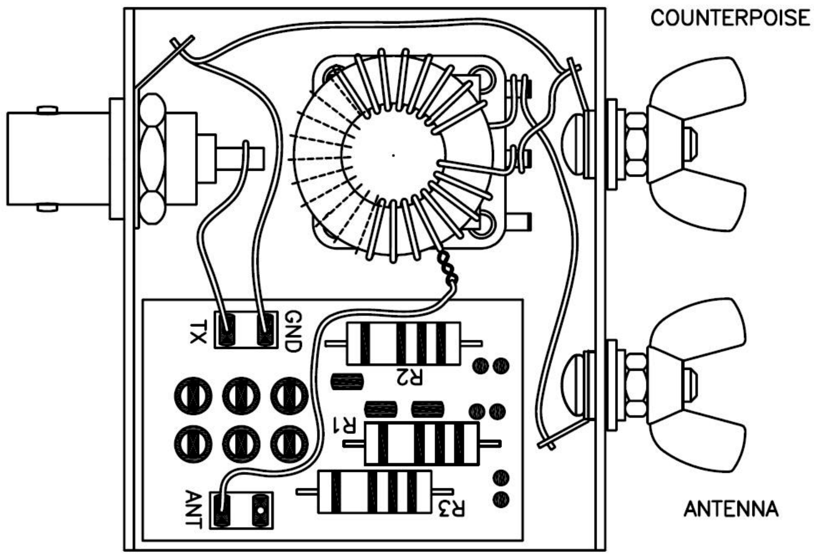
Wire only the two ends of the toroid winding to the poly-varicon as shown, Leave the tap unsoldered for now.

Pre-wire the previously assembled SWR indicator as shown with 3” long pieces of hook-up wire.

Install the pre-wired SWR indicator as shown here and secure it to the chassis with the remaining toggle switch nut.







Final Assembly Steps

The above diagram will assist with making the final connections to complete your SOTA tuner:

Mount the poly-varicon/toroid assembly to the chassis cover with the two 2.5 x 4 mm screws and the supplied lockwashers.

The washers are necessary to provide sufficient clearance for the polyvaricon plates. They are a relatively tight fit and may need to be gently pressed in place.

Solder the wire from the center connection of the poly-varicon to the counterpoise lug.

Solder the wire from the side connection of the poly-varicon to the antenna lug.

Solder the “ANT” wire from the swr indicator to the toroid tap.

Solder the “TX” wire from the swr indicator center connection of the BNC connector.

Solder the “GND” wire from the SWR indicator to the BNC ground lug.

TIP: Before proceeding test with the toggle switch in the “OPERATE” position to be sure there is no continuity between the wingnuts and the case.

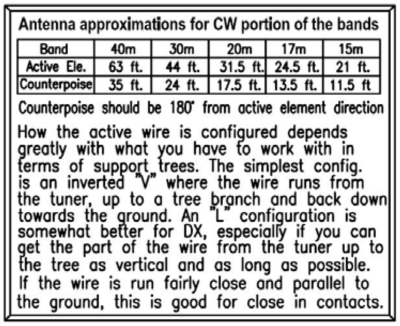
Solder a wire from the BNC ground lug to the counterpoise ground lug.

Fit the bottom half of the case to the top and secure it with the two flat head 4-40 screws.

Install the knob on the poly-varicon shaft using the knob set screw.

Congratulations this completes assembly of your SOTA Tuner!

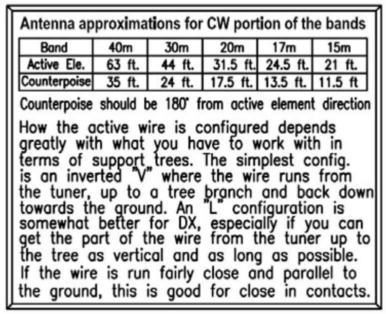
Optional label for back of case


Antenna approximations for CW portion of the bands

Band	40m	30m	20m	17m	15m
Active Ele.	63 ft.	44 ft.	31.5 ft.	24.5 ft.	21 ft.
Counterpoise	35 ft.	24 ft.	17.5 ft.	13.5 ft.	11.5 ft

Counterpoise should be 180° from active element direction

How the active wire is configured depends greatly with what you have to work with in terms of support trees. The simplest config. is an inverted "V" where the wire runs from the tuner, up to a tree branch and back down towards the ground. An "L" configuration is somewhat better for DX, especially if you can get the part of the wire from the tuner up to the tree as vertical and as long as possible. If the wire is run fairly close and parallel to the ground, this is good for close in contacts.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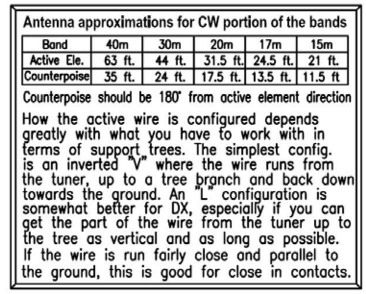
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If you want to have this chart on your tuner, print out the above labels and scale when printing as necessary to fit the bottom of the chassis.

Three sizes are provided to approximate the correct size to fit the case regardless of you printer scaling.

We recommend protecting this label with a piece of clear packaging tape, or peel and stick laminate film.

You can attach it to the back of the case with two-sided tape.

Using your SOTA Tuner

Start with a light weight wire a few inches longer than the lengths suggested for the band you wish to operate and test to see if a good match can be achieved as indicated by the LED completely extinguishing as the tuning knob is turned over its range.   If not, shorten the wire in one inch increments and retest.

Note: The values provided in the table above are suggested starting points, not absolutes and your wire lengths may vary due to many conditions.

Note: Some users use short counterpoises of approximately 0.1 wavelength successfully with endfed half wave antennas.

The condition and nature of the ground as well as the angle of elements in respect to ground, can all affect the overall length wire needed to achieve a good match.

We recommend that you test the SOTA tuner and note what works best for your conditions.

How the wire is deployed will depend on what is available for support such as trees and/or structures.

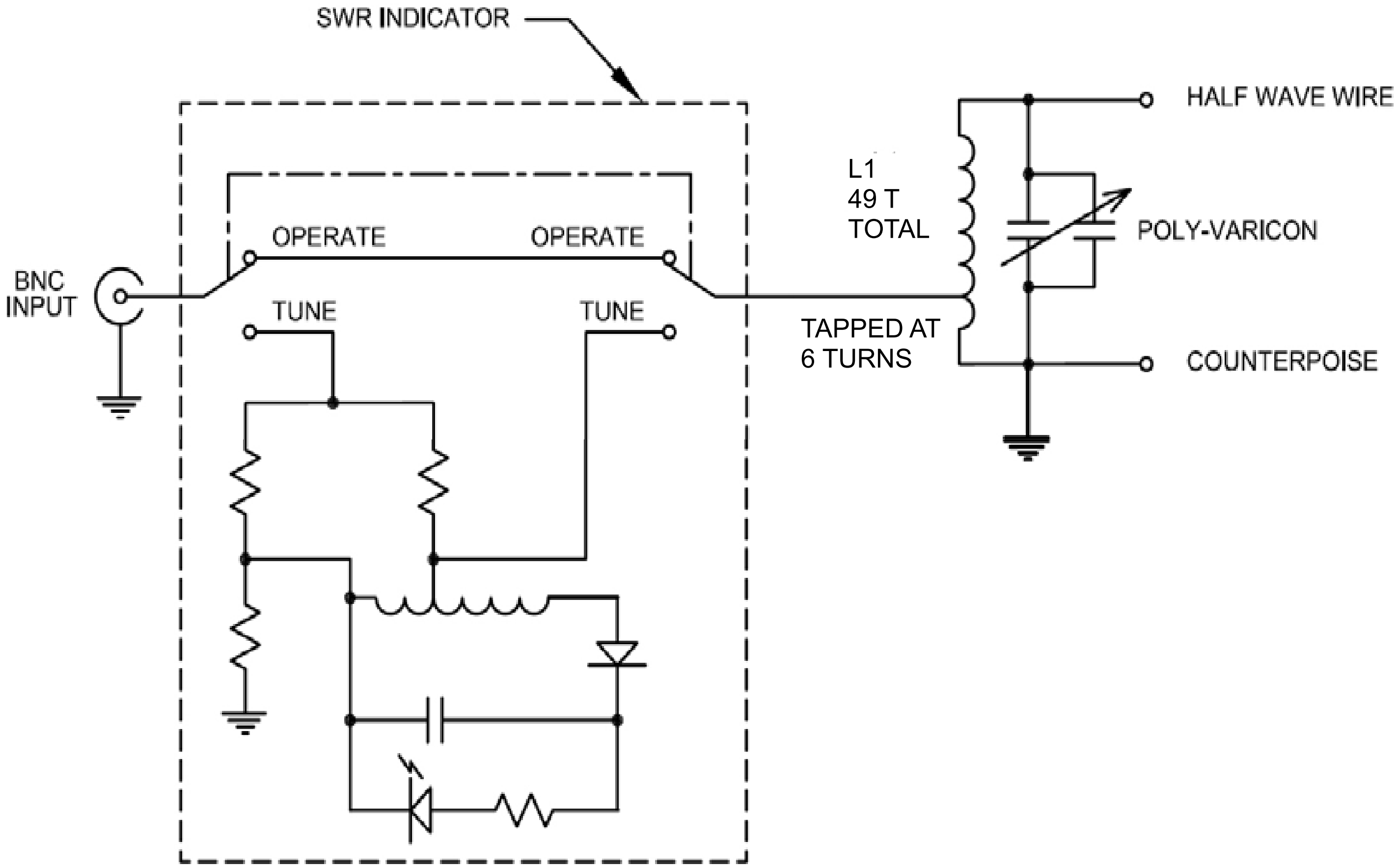
The simplest configuration is an inverted "V", where the active element runs from the antenna connection of the tuner, up to a tree branch, and back down towards the ground.

An "L"configuration for the active element is somewhat better for DX, especially if you can get the part of the wire from the tuner up as vertical as possible.

If the wire is run horizontally and fairly close to the ground, the signal will mostly be directed upward and therefore will be better for close in contacts, especially on the lower frequency bands.

Try to keep the counterpoise 180 degrees from the active element.

Schematic



SWR INDICATOR
BNC
INPUT
OPERATE
OPERATE
TUNE
TUNE
L1
49 T
TOTAL
TAPPED AT
6 TURNS
HALF WAVE WIRE
POLY-VARICON
COUNTERPOISE

TRF RADIOS
Part 1
The ZN414 / MK484 I.C. & The Matchbox Radio

MDS975 www.mds975.co.uk

Having difficulty in finding components? I have added some ideas for component sources here.
Sources For Older Components LINKS to Other Great Websites

BUILD YOUR OWN MINIATURE 'MATCHBOX' RADIO

Worried About Soldering? Don't Be:

For some simple ideas on solderless construction techniques have a look at the Crystal Sets 2 and the Crystal Sets 5 pages. While the ultimate miniaturisation cannot be achieved with solderless techniques, it is still possible to produce a working project in this way. When constructing these small electronic projects it will be necessary to determine the exact value of resistors, which are colour coded, and capacitors, which sometimes have confusing numbers on them. I have included a table for both Resistor Colour Codes and a Capacitor Conversion Table HERE.

TRF RADIOS (Part 1)

INTRODUCTION

In the very early days of wireless a TRF (Tuned Radio Frequency) radio was the next step up from a crystal set. It offered amplification of both the radio frequency and the audio frequencies so that more stations could be received more strongly and the sounds produced would be amplified sufficiently to power a loudspeaker.

From the 1920' to the 1940's it was the glass *thermionic valve*, the forerunner to the transistor, that was the only component available for such amplification. A valve is quite a large device, about the size of an eggcup and looking a little like a small lightbulb. The valve needs its internal working parts , the anode and cathode, to be heated to operate (hence the term THERMionic) and so a valve contains filaments that glow red hot. Valve radios would consequently get quite warm and therefore

use quite a lot of power requiring several large batteries or mains power to operate. The valve filaments needing just a few volts to get hot, while the voltage required to obtain a flow of electrons in the anode would need 100 volts or more.

Later radios dispensed with the TRF technology in favour of the more sensitive and selective 'superhet' (supersonic heterodyne) method. If the set is in good working order the wireless listener will no doubt be rewarded with a wonderfully rich and warm sound quality. Many of these original valve sets had beautifully hand-crafted wooden cabinets which would often enclose a large loudspeaker that produced the fine sound quality.

Old mains valve radios can be very dangerous to dismantle and 'play around' with as they invariable have a live metal chassis. As this chassis will be at 230 volts mains potential the effect of a mis-positioned digit could be fatal, so I advise against this practice. Instead have a go at building a modern day TRF radio using the latest solid state (i.e. silicon transistors) technology, which operates at low power and with very low current consumption. It was not until the introduction of the transistor in the mid 1950's that radio sets could be made smaller and truly portable and consume much less power, making battery operation a practicality.

Building a TRF set today is quite straightforward as small transistors or IC's (Integrated Circuits containing several transistors and other components in a small sealed device) will require only battery power in the order of 1.5 to 6 or 9 volts to operate.

As mentioned a TRF radio has its limitations and was superceded by the *Superhet*, which is a principle used in all modern receivers, but the results achieved with modern components can be outstanding.

The TRF radios described here all use transistorized circuits, though some of the the circuit layouts are fairly similar to some early simple valve TRF radios.

BUILD A RADIO IN A MATCHBOX !

The rather battered magazine cover of Everyday Electronics
http://www.epemag3.com/

THE MATCHBOX RECEIVER

When my dad came home one night in the 1970's with a copy of Everyday Electronics magazine I was fascinated by an article describing how to home-build a radio so small that it would fit into a matchbox. I was a schoolboy taken with the hobby of radio and had recently built a regenerative radio described in the Ladybird book "Making A Transistor Radio". This book was given to

me as a birthday present from an aunt and the method of construction used was a simple solderless breadboard that trapped the component leads with number 6 brass wood screws and screw cups.

The Matchbox Receiver, on the other hand, required careful soldering of the components into a circuit board to achieve the small size needed to fit into a case as small as a matchbox. I did not have a soldering iron, I was too young.

Dad *did* have a soldering iron, it was not electric though and had to be heated over a gas flame! We spent several hours in the kitchen heating this big iron over the gas hob and soldering the tiny components onto the circuit board.

The matchbox receiver uses just two main components, one that I was familiar with - a transistor (the BC107), and a component new to me at the time, an Integrated Circuit (I.C.) containing no less than ten transistors inside a tiny TO-18 style can. The I.C. used is the Ferranti ZN414 which contains a high gain RF amplifier stage offering up to 72dB of gain, a detector stage and a.g.c. stage.

The ZN414 has a very high input impedance of around 4meg Ohms which minimizes any loading of the tuned circuit thereby improving selectivity, which is important when being used in a simple TRF radio such as is being described. The useable tuning range available from the ZN414 is from 150kHz (Long Wave) through Medium Wave and up to 3000kHz. Current consumption is tiny, making it very suitable for the matchbox radio powered by a silver-oxide button cell.

Once dad and I had soldered everything together and assembled the parts into a matchbox I think that we were both amazed that it worked! We received BBC Radio Four on 285 meters, Radio Three on 464 meters, Radio One on 247 meters, Radio Birmingham on 206 meters and BRMB Radio on 261 meters.

A Matchbox Radio
(This particular one uses the ZN415 IC - see the notes further down the page)

In 1975 the idea of being able to build a complete working radio that would fit inside an ordinary matchbox seemed absolutely amazing. Today it is run of the mill of course, but the article from Everyday Electronics of Sept 1975 is still really interesting.

As mentioned, it uses the Ferranti ZN414 integrated circuit which is no longer available, but the direct replacement MK484 can be used with confidence and is widely available from many outlets including Bowood Electronics , as are a ferrite rods, fixed capacitors, resistors, preset pots and 500pF trimmers. You may also have some similar and useful components in your junk box. The circuit could still be made up using a miniature tuning capacitor salvaged from a discarded Chinese pocket radio. See the alternative circuits too.

Another equivalent to the ZN414 and MK484 is, I am informed, the TA7642 which is available from Rapid Electronics.

I have now built a couple of these radios and another one using the ZN415 I.C. which includes an additional buffer stage of audio amplification.

So have a look at the article a little further down the page, I'm sure that you'll find it fascinating.

DID YOU KNOW?

Electronic component sizes are be effectively reduced by half every 18 months!
The same progress in design and manufacture enables computer processor (CPU) speeds to be doubled every 18 months.

This effect of miniaturization is quite noticeable even when working with the very ordinary components involved in the construction of this matchbox radio project, i.e. components with leads intended for use on an ordinary circuit board.

When I first built this radio in the late 1970's the resistors and capacitors were two or three times the size of the ones I used when re-building the project with current components. This helps greatly with construction inside a matchbox.

However this process of miniaturization has progressed beyond the 'ordinary' components that are used in everyday 'home-brew' projects, since there is a limit to how small such a component can be and remain usable on standard circuit boards. Today's powerful personal computers, laptops, mobile 'phones and digital cameras are all made possible by the use of very large scale integrated circuits and miniaturized 'surface mount' components such as resistors and capacitors that are the size of a pin head! These are rather more difficult to work with for the home constructor.

Photograph showing how components have been reduced in size as time has progressed
The top two are 0.01µF ceramic disc capacitors, the left one from the 1970's and the right one from 2003
The bottom two are resistors, the left one a 0.5 watt from the 1970's and the right one from 2003

BUILD A MATCHBOX RECEIVER !

THE EVERYDAY ELECTRONICS 'MATCHBOX RECEIVER' ARTICLE

MATCHBOX RECEIVER

BY F.G.RAYER

A miniature m.w. receiver using an integrated circuit to give good reception

A PORTABLE radio receiver able to give very good headphone reception from its internal ferrite aerial is nowadays quite easily constructed to fit inside a case the size of a matchbox due to miniaturisation of components. In fact the prototype receiver was fitted into an empty *matchbox*, assembly being in the tray and the outer part serving as a cover.

Tuning coverage is about 550 kilohertz to 1550 kilohertz, which is typical for the medium wave band.

CIRCUIT

The circuit diagram of the receiver is shown in Fig. 1. The ferrite aerial L1 forms a tunable parallel resonant circuit with compression trimmer C1. The output from this network (r.f.) is fed to integrated circuit IC1 which is a ZN414. This is a multistage amplifier and detector and processes the incoming modulated r.f. and extracts the audio signals making them available at the output lead. Resistor R1 is the necessary feedback resistor for IC1 and R2 and VR1 form the load for IC1.

The output from the integrated circuit is coupled, via C4, to audio amplifier TR1 which provides a considerable increase in volume.

Power is from a single 1.4V mercury battery. As there is no space for a conventional on/off switch, the output jack SK1 is so arranged that closure of the contacts B and C switches on the receiver. It is thus switched on by plugging in the headphones, and switched off by withdrawing the plug.

OUTPUT SOCKET

The output jack socket should be a switched type and can be 2·5mm or 3·5mm, but has to be

Components....

Resistors
R1 100kΩ
R2 470Ω
R3 680kΩ
All ¼W carbon ± 10%

SEE SHOP TALK

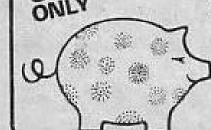
Capacitors
C1 450pF compression trimmer
C2 0·01μF plastic or ceramic
C3 0·1μF plastic or ceramic
C4 0·05μF plastic or ceramic

Semiconductors
IC1 ZN414 a.m. radio integrated circuit
TR1 BC107 silicon *npn*

Miscellaneous
VR1 1kΩ miniature carbon linear preset potentiometer
B1 MP675 1·4V mercury cell or similar
SK1 switched jack socket, 2·5mm or 3·5mm (see text)
Plain matrix board, 0·15in. 9 x 8 holes; ferrite-rod 37mm x 9mm (⅜in) diameter; 32 s.w.g. enamelled copper wire; knob (see text).

FOR GUIDANCE ONLY

ESTIMATED COST* OF COMPONENTS
excluding V.A.T.



£2.40

*Based on prices prevailing at time of going to press

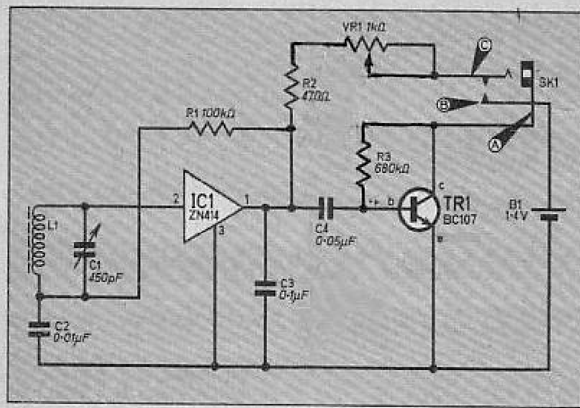


Fig. 1. Complete circuit diagram of the Matchbox Receiver

arranged so that the switchable contacts close when the plug is inserted. Jack sockets are normally made so that inserting the plug causes the contacts to open. If the required type is not readily available, the standard type should be modified. Some types of socket cannot be modified in this way so be alert when buying this component and inspect it to see if the modification can be carried out.

AERIAL AND TRIMMER

The winding L1 is 60 turns of 32 s.w.g. enamelled copper wire wound side by side on a ferrite rod 37mm long and 9mm ($^3/_8$in) in diameter. Winding should begin 3mm from one end of the rod, and the end turns secured with adhesive. (The whole winding should not be covered with adhesive.)

Trimmer C1 as supplied has an adjusting screw for setting by screwdriver. This should be replaced by a 6BA bolt (about 25mm long), taking care to retain the insulated and metal washers under its head. The bolt projects enough to take a 6BA lock-nut and knob or metal or insulated terminal head, see Fig. 3. This is for hand tuning.

The lock-nut is positioned so that the compression trimmer plates can spring fully open, or tuning coverage will be restricted and the high frequency end of the band cannot be reached.

COMPONENT BOARD

The prototype unit was built using 0·15 inch plain matrix board size 9 by 8 holes. The layout of the components on the board and the interconnecting wires on the underside of the board are shown in Fig. 2.

Begin by inserting a few components at a time, beginning with the resistors and capacitors and carrying out the underside wiring as you go along. Pay special attention to the lead-out connections when soldering IC1 in position and use a heatshunt on the leads when soldering; similarly with TR1.

Joints and leads should be flat against the board so as to avoid raising the board more than about a millimetre or so above the base of the matchbox tray when mounted in position. Sleeving is necessary on the lead on the underside from C3 to battery negative, see Fig. 2.

As the battery has a long life, connections are soldered directly to it; the case is the positive terminal. The ferrite rod assembly is secured to the component board with adhesive.

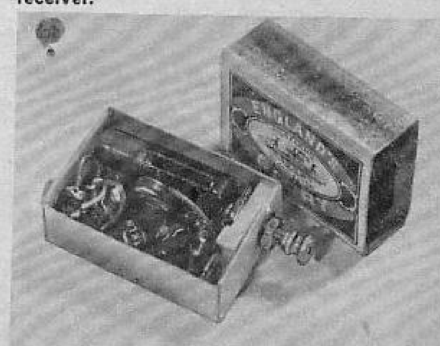
When all the board mounted components have been secured in position, SK1 and C1 should be wired in.

TESTING AND SETTING UP

Best results, and most comfortable listening, will be obtained with a complete headset, although a single minature earphone is of course

Continued on page 493

Photograph showing the construction of the receiver.



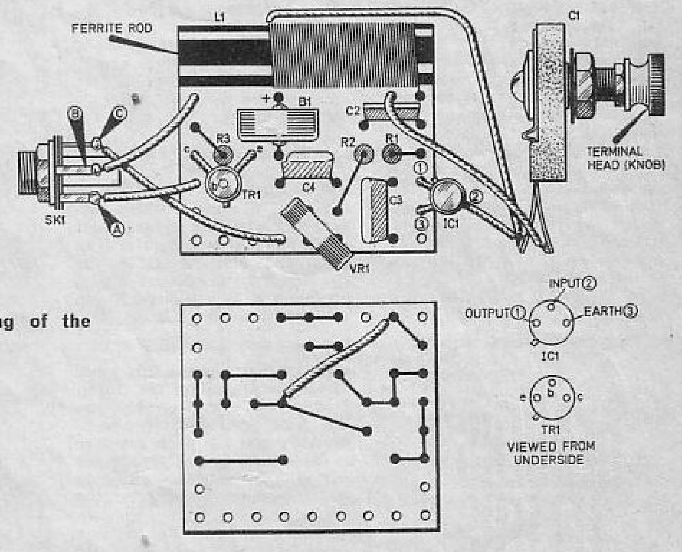


Fig. 2. Layout and wiring of the Matchbox Receiver.

Continued from page 485

easy to carry at other times. Medium or high impedance units, or headphones of about 2,000 ohms, are most suitable.

With the 'phones plugged in, adjusting C1 should tune in the stations which are best received in the locality. Some may be too loud, causing overloading, and this is corrected by turning the receiver to reduce signal pick up by the ferrite rod, if needed.

Potentiometer VR1 is adjusted with a small screwdriver. When VR1 is at a low value, or zero, volume is greatest, but oscillation may accompany some signals. If so, turn VR1 to increase resistance so that oscillation ceases. The setting is not critical. Later readjustment of VR1 will give some extra life for a failing battery.

All that remains to be done is fit the assembly into a matchbox—or other case if you desire—and the receiver is complete and ready for use.

Everyday Electronics, September 1975 493

New products and component buying for constructional projects

SHOP TALK

By Mike Kenward

Matchbox Receiver

Parts for the *Matchbox Receiver* must of course all be small—remember this point when buying the capacitors in particular. The output socket also acts as the on/off switch and must be of a particular type which is modified—see text.

The trimmer used for tuning can be modified to provide a tuning "knob" or a special conversion spindle can be purchased from Home Radio. The short piece of ferrite rod required is not likely to be sold as such and will have to be cut from a larger piece; do this by filing a notch around the rod at the required point and breaking off the section over the edge of a table.

http://www.epemag3.com/

Notes About Components On The Above Article:

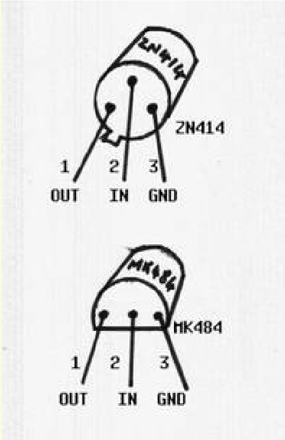
- **The ZN414 I.C. can be replaced with the current MK484 chip or the TA7642.**
- **The BC107 transistor can be replaced with a BC547, a BC182 or a ZTX300 (and other general purpose devices may work equally well).**
- **I found that the 680K biasing resistor could be replaced with a 470K or even a 100K without detriment.**
- **I used a 1.55 Volt Silver Oxide battery and found that the 1K preset potentiometer must be replaced with 10k preset pot to give an adequate range of control over gain.**
- **When using a Crystal Earphone a resistor of between 4.7k and 10k needs to be included from the collector of the BC107 to the positive rail (after the switched jack socket) i.e. across the earphone terminals. This will not effect the use of 1000 ohm earphones / earpieces.**

- **Also, have a look at the further information below for some more tips.**

SO GO AHEAD... GET BUILDING!

PARTS LIST

1 : MK484 (or TA7642 or ZN414) Integrated Circuit
1 : BC107 or BC547 or ZTX300 Transistor
1 : 500pF Miniature Postage Stamp Trimmer Capacitor
1 : Crystal (Ceramic) Earphone
1 : 0.01 µF Ceramic (or similar) Capacitor (103)
1 : 0.1 µF Ceramic (or similar) Capacitor (104)
1 : 0.047uF (0.05µF) Ceramic (or similar) Capacitor (473)
2: 100k Ohm ¼ watt Resistor



The Pin-Out Arrangement of the ZN414 and MK484 Integrated Circuits. The TA7642 is apparently the same as the MK484.

Try to avoid overheating the IC when soldering and keep the wiring of the whole circuit as neat as is possible to avoid unwanted oscillations that could occur with untidy wiring.

1 : 470 Ohm ¼ watt Resistor
1 : 4.7k Ohm ¼ watt Resistor (optional)
1 : 10k Miniature Preset Potentiometer
1 : 10mm Dia Ferrite Rod 100 or 150 mm long
1 : Reel of 0.5mm (approx) Enamelled Copper Wire
1 : 3.5 mm Jack Socket (for earphone)
1 : AA Battery Holder
1 : 1.5 Volt AA Battery
1 : On/Off Switch (optional)
1 : Tagboard or Verostrip board

BOWOOD ELECTRONICS
is a useful source for many of these components

You May Also Try:
J Birkett, The Strait, Lincoln for surplus items such as capacitors

Here are links to more component suppliers >>

AERIAL COIL DETAILS

MEDIUM WAVE: 60 to 65 Turns of 0.5 mm dia enamelled copper wire on a 10mm dia Ferrite Rod of about 35 to 40 mm long.

LONG WAVE: As above but with 250 turns of wire.

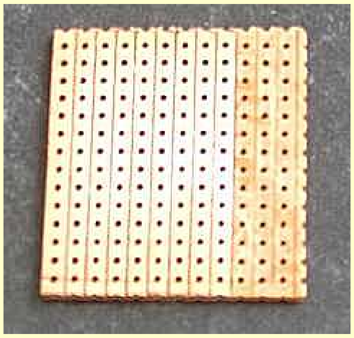
MY REBUILT MATCHBOX RECEIVER

My original matchbox receiver had got rather battered and worn, so being as I needed to solder a new battery into place I took the opportunity to refurbish the radio. I used the original Ferranti ZN414 i.c. , BC107 transistor and 500pF trimmer capacitor used for tuning. The resistors and capacitors I replaced with new smaller ones and I also replaced the circuit board and the 3.5mm jack socket with a new one as the original looked rather corroded. A 4.7k resistor was also included across the earphone output as I use these radios with a crystal earpiece, as mentioned above. I also replaced the medium wave coil with a Long Wave coil (purchased from Maplin Electronics) so that the radio could tune into 198 kHz for BBC Radio Four and also 252 kHz for RTÉ Radio One.

(I built another matchbox radio, using the newer MK484 i.c, and this covers Medium Wave. See further down this page. A TA7642 could also be used).

The photo above is a little trip through England's Glory matchbox history. The box top left is from 2004, and the box top right is probably from the 1990's while the box at the bottom is probably from the early 1980's. Incidentally England's Glory matches are now made in Sweden - so shouldn't they be called Sweden's Glory?

SCRAPE OFF THE VERO-STRIPS UNDERNEATH THE FERRITE-ROD AERIAL!



The photograph above shows the underside of the VeroStrip board that I used to build the matchbox radio. Note how three rows of copper strips have been removed using a sharp blade. The ferrite rod aerial sits above this area and leaving the copper in place reduces the "Q" (the effectiveness) of the tuned circuit very markedly.

Leaving the strips in place would result in poorer selectivity and sensitivity of the radio and thereby rather poor reception. I strongly recommend removing any strips from immediately below the ferrite rod aerial when constructing such a radio. Also keep the aerial away from any other metal objects that will mar the reception.

Above photo is a close up look at the re-built ZN414 matchbox radio
with the new Long Wave tuning coil.

DON'T DESPAIR

Don't despair if you cannot find some of the components required for the Matchbox Receiver. The resistors will be no problem, of course, and can be 1/4 Watt, 1/2 Watt or 0.6 Watt at any tolerance. The capacitors can be Ceramic Disc, Resin Dipped Ceramic or Polyester and the values stated should not be varied for best performance.

As mentioned elsewhere the ZN414 is no longer available but the MK484 i.c. is widely and there should be no problem obtaining one of these. The TA7642 is another equivalent to the ZN414.

There will be no difficulty in finding a small piece of 10mm diameter ferrite rod and some 0.5mm dia, enamelled copper wire for the aerial.

There may be a little difficulty in finding the 500pF postage-stamp trimmer, and the 6BA brass screw and nut to extend the tuning shaft, but some careful searching should be rewarded with the necessary items.

Alternatives To The 500pF Trimmer For Tuning

Since components are so small these days, there will be an opportunity to use a miniature 200pF (approx) poly-dialectric (polyvaricon) tuning capacitor of the type that may be salvaged from a pocket transistor radio and that is generally more widely available from component suppliers. This would take up more space in the matchbox and the tuning knob would protrude from the back face of the box rather from one end. With careful re-arrangement of the components and some neat soldering there is a very good chance that everything could be still be accommodated in a matchbox, though I have not tried this yet.

Another alternative would be to have the matchbox receiver permanently tuned to a favourite station. The tuning circuit could then consist of a fixed capacitor of perhaps 50pF or 100pF or even a miniature trimming capacitor of similar value. The required favourite station could then be set by experimenting with the number of turns on the coil, and 'fine-tuned' with the small value trimmer, if that is what is used. This is just an idea but then the receiver would easily fit inside a matchbox.

The 3.5 jack socket has to be the open type, i.e. not enclosed in a plastic case, so that the switching operation can be changed from opening when the earphone plug is inserted, to closing when the plug is inserted. A pair of pointed nose pliers is all that is required to bend the switching contacts into the required position.

ANOTHER OF MY MATCHBOX RADIOS

This One Using The MK484 IC

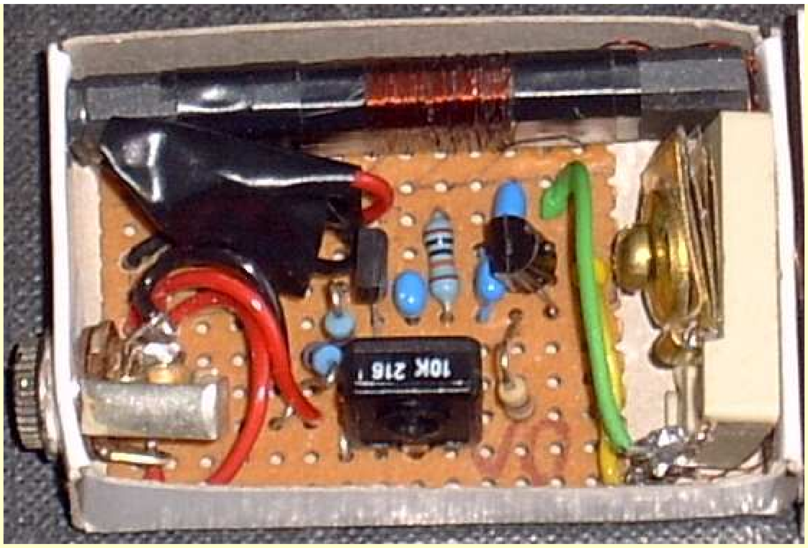
I have recently built another matchbox receiver, which is shown above and uses the MK484, a replacement for the ZN414. This radio uses a ZTX300 transistor as the audio output device which, in this case, has a 100K biasing resistor, rather than the 680K resistor specified in the Everyday Electronics magazine article above. In fact a BC107, a ZTX300 or a BC547 transistor can be used in this circuit, with a 100k biasing resistor all with equally good results.

I strongly recommend using a crystal earphone rather than the high impedance magnetic earphone referred to in the article since such earphones are almost impossible to come by. My own Matchbox radio will drive a pair of 32 Ohm 'Walkman' type headphones to reasonable volume when the two earpieces are wired in SERIES to provide a 64 Ohm load, but a crystal earphone is much MUCH louder which means that more of the weaker stations can be heard.

I therefore recommend the use a crystal earphone, however a 4.7K Ohm resistor (up to about 10K works) needs to be soldered across the earphone output; i.e. between the collector of TR1 (the BC107, BC547 or ZTX300) and the positive (+ve) rail - before the preset potentiometer and after the on/off switch (or switched jack socket if that method of switching is employed, as it is in my radio).

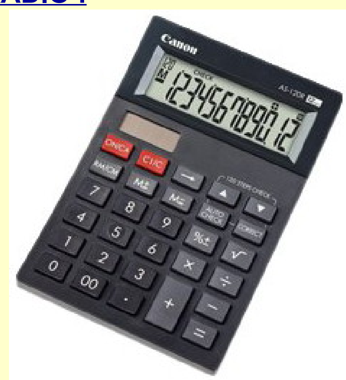
I would also recommend the use of a 10k preset potentiometer to set the gain, as my radio was far too loud and rather distorted when using a new 1.55 volt silver oxide button cell and even a 4.7K preset potentiometer could not introduce enough resistance into the circuit to sufficiently reduce the gain. The 10K pot works very well in my set.

As with all these designs don't forget to scrape off the copper strips from the Veroboard below the area where the ferrite rod aerial will be mounted. Failure to remove these strips will not prevent the radio from working, but the performance of the tuned circuit will be marred.



Photograph showing a close-up of the inside of my Matchbox Radio
The tiny silver oxide battery is covered in black insulating tape.
The skeletal jack socket has been modified so that the contacts make a circuit when inserting the earphone jack plug rather than breaking the circuit as is usually the case.
This then automatically switches the radio on when the earphone is plugged in.

SOLAR POWERED MK484 MATCHBOX RADIO !



Solar Power !

Hi Mike,

I was very pleased to read about the ZN414 Matchbox radio and its variants (MK484 & TDA7642) as I have experimented with it before. Readers might be interested in the fact that this little radio can even be driven using an old solar panel salvaged from a pocket calculator! These panels usually provide up to 2 Volts being exposed to bright daylight and a current of 1mA or more.

If you are worried about voltage overload simply add a 1.5 V zener diode or a rechargeable button cell in parallel which will cut down Voltage, thus protecting your precious ZN414 and avoiding self oscillating.

With best regards from Germany, Dietmar DH7AMQ [April 2013]

Thanks Dietmar - What an excellent idea!

SOME ALTERNATIVE MK484 (ZN414) (TA7642) CIRCUITS
(Which Also Work Really Well!)

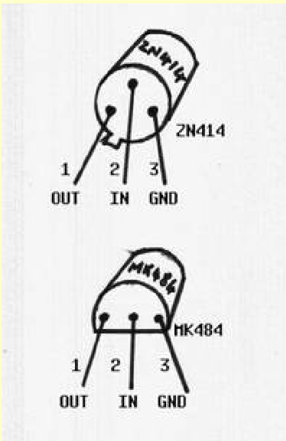
Even simpler than the 'Matchbox Radio' described in the above 1975 Everyday Electronics article would be to use the circuit below which omits the amplification (BC107 transistor) stage. The ZN414, TA7642 or MK484 is still able to drive a simple Crystal earpiece to reasonable volume, though obviously not as loud as with the additional transistor included. This approach would make it even easier to assemble the receiver into a matchbox. I have also constructed this set (though not inside a matchbox) and it works brilliantly with a simple crystal earpiece. I decided to use a 4 inch (10cm) long ferrite rod, which produces better signal pick-up so that stations will be more clearly heard.

The aerial coil consists of 60 turns of 0.56mm diameter enamelled copper wire which gives good coverage of the Medium Wave band even when using a small 220 pF tuning capacitor. Battery power is again only 1.5 volts, this time I used a penlight AA cell which will last for a very very long time indeed. The 10k Ohm preset pot sets the internal gain of the MK484 integrated circuit and while not critical in many cases careful adjustment is needed in strong signal areas to help prevent overloading.

Keep construction of the circuit very neat with component leads as short as is practicable. Ideally the radio should be built on a

small piece of VeroStrip, but if you wish to experiment with components and values then an ordinary piece of tag-board will be quite suitable. A 6 x 6 tag board will be more than adequate for this circuit and I have built these sets in this way very successfully, but bear in mind to keep the output components and battery away from the coil and tuning capacitor.

Other component values should be adhered to to obtain best results, the 0.1uF capacitor at Pin 1 (output) of the MK484, the 100k Ohm resistor and the 470 Ohm resistor should not really be changed. The 0.01µF capacitor can be experimented with and could be between 0.01 and 0.0068 µF. The 0.05µF output de-coupling capacitor is not too critical and the resistor across the crystal earpiece could be 2.7K Ohm 4.7K, 6.8K perhaps up to 10K depending on the particular earphone used. I found that a 2.7K resistor allows my crystal earphone to work very effectively indeed. The battery voltage should not be changed and should be between 1.4 and 1.6 volts. Either an original Ferranti ZN414 IC or the later MK484 IC can be used in these circuits, the newer MK484 may work even better than the excellent, but now obsolete, ZN414.



The Pin-Out Arrangement of the ZN414 and MK484 (TA7642) Integrated Circuits.

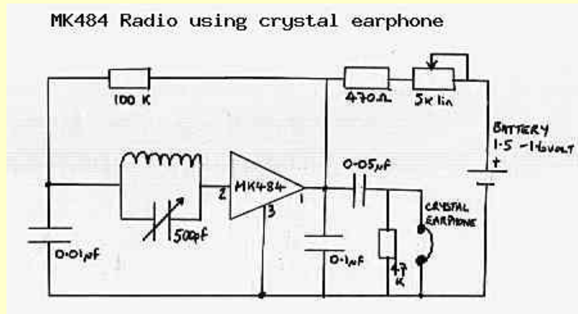
Try to avoid overheating the IC when soldering and keep the wiring of the whole circuit as neat as is possible to avoid unwanted oscillations that could occur with untidy wiring.

AERIAL COIL DETAILS

MEDIUM WAVE: 60 Turns of 0.5 mm dia enamelled copper wire on a 10mm dia Ferrite Rod of between 100 and 150 mm long

LONG WAVE: As above but with 250 turns of wire with the coil ideally being shunted with a 220k Ohm resistor

Maplin Electronics have been selling a 10mm diameter ferrite rod with a pre-wound medium wave and long wave coil included and this may provide another option. Ferrite rods are also available from Bowood Electronics.



+ See note below

PARTS LIST

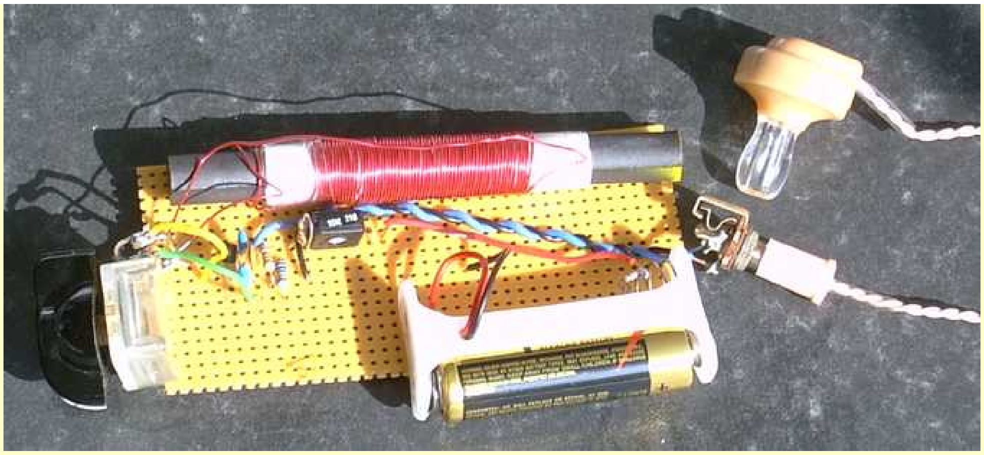
1 : MK484 (or TA7642 or ZN414) Integrated Circuit
1 : 220pF or 500pF Tuning Capacitor
1 : Crystal (Ceramic) Earphone
1 : 0.01 µF Ceramic (or similar) Capacitor (103)
1 : 0.1 µF Ceramic (or similar) Capacitor (104)
1 : 0.047uF (0.05µF) Ceramic (or similar) Capacitor (473)
1 : 100k Ohm ¼ watt Resistor
1 : 470 Ohm ¼ watt Resitor
1 : 2.7k (or 4.7k) Ohm ¼ watt Resistor
1 : 10k Preset Potentiometer
1 : 10mm Dia Ferrite Rod 100 or 150 mm long
1 : Reel of 0.5mm (approx) Enamelled Copper Wire
1 : 3.5 mm Jack Socket (for earphone)
1 : AA Battery Holder
1 : 1.5 Volt AA Battery
1 : On/Off Switch (optional)
1 : Tagboard or Verostrip board

BOWOOD ELECTRONICS
is a useful source for many of these components

You May Also Try:
J Birkett, The Strait, Lincoln for surplus items such as capacitors

Here are links to more component suppliers >>

+ Our correspondent Chas Castagana, in the USA, had some trouble with this circuit he writes: I constructed this circuit as close to your spec's as I could, ...perhaps it may be better to feed the output into an external transistor amplifier stage.
I think Chas may have been using headphones which possibly may not work as well as a Crystal Earphone that I had intended.
This design can certainly be fed into a discrete transistor amplifier stage and will give excellent results in this way, but even connecting the crystal earphone between the output and ground (as shown) I find that there is a more than usable audio output on all local stations. It is worth including the circuit here due to its simplicity and good performance. it may also be worth experimenting with connecting the crystal earphone between the output, via 0.05 uF capacitor, and the positive rail (i.e. to the positive side of the battery) and connecting the 47k Ohm resistor across the earphone output. Either way I don't think constructors will be disappointed. Thanks Chas for the input!

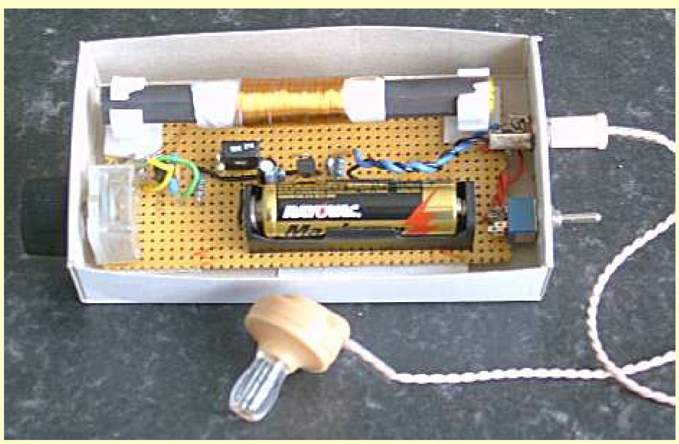


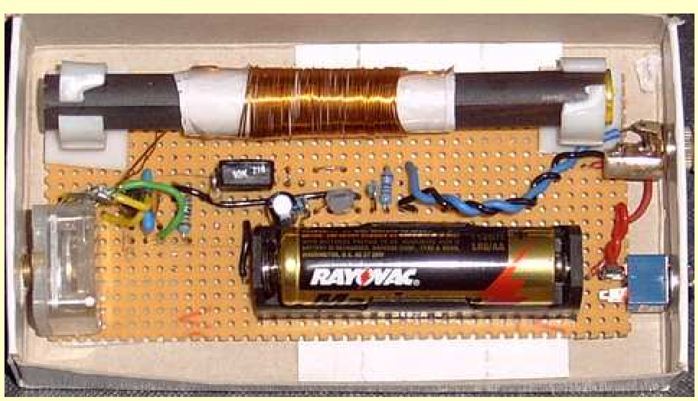
The Working Single Chip MK484 Radio Constructed On A Piece Of VeroStrip

At our location I can receive the three national stations, BBC Radio Five Live, Talk Sport and Absolute (Virgin) Radio from a main transmitter about 25-30 miles away plus BBC Five Live from a main transmitter about 80 miles away on 909 kHz. Two low power local stations (990 kHz 0.1 kW and 828 kHz 0.2 kW) are also received at good strength from their transmitters located 6 miles away. Before it closed, a community station on 1350 kHz at only 0.001kW located about 4 miles away could also be received. Additionally three other local radio transmitters (3 to 6 kW) about 15-20 miles away were also receivable. At night a number of other broadcasts can be heard easily, e.g. 1440 from Luxembourg and 1512 kHz from Belgium and some others such as 567 kHz from Eire and 675 kHz from The Netherlands.

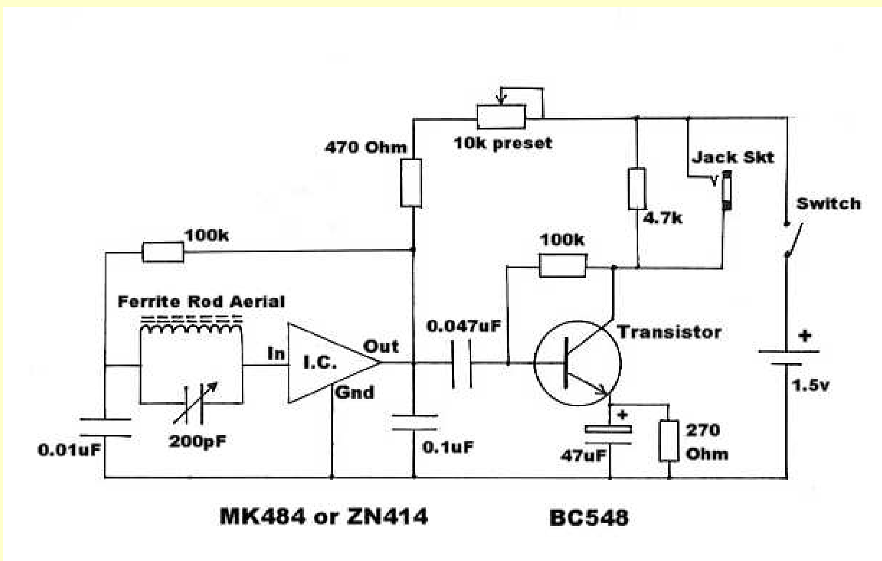
ADDITIONAL AUDIO AMPLIFICATION USING THE BC548 TRANSISTOR

The MK484 receiver shown below uses a BC548 transistor as the audio output stage. It also uses a larger ferrite rod aerial for better signal pick-up, a standard "AA" battery cell and a widely available miniature polyvaricon tuning capacitor of approximately 200pF for ease of construction. This really is a superb radio!





Above the completed "Cook's Matchbox Radio"
Housed in a larger matchbox to accommodate a longer ferrite rod aerial for improved pick-up and a standard "AA" battery cell together with the more orthodox polyvaricon type tuning capacitor. The larger housing also makes construction a little easier.
See the circuit diagram for this radio below:



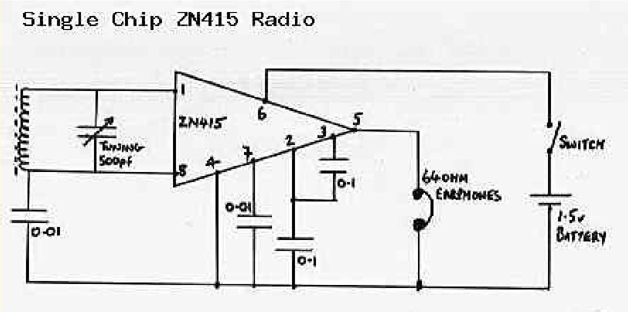
Above: Circuit Diagram For The Excellent MK484 (or TA7642 or ZN414) with the BC548 transistor stage of amplification.

The tuning capacitor can be any standard type of between about 200pF and 500pF and the polyvaricon type commonly found in pocket radios and should be available new from many component suppliers. A crystal earpiece should be used, although excellent results may be obtained with a pair of good quality and sensitive 32 Ohm 'Walkman' type headphones. If these earphones are to be used, the 32 Ohm earpieces must be wired in SERIES so that the total load is 64 Ohms. This can be arranged by using a stereo jack socket and connecting the output across the first two (small) rings of the headphone plug and making no connection to the upper (longer) part of the plug which is the common/ground connection of the 'phones.

THE ZN415E and ZN416E

Have a look at the circuit below which uses the ZN415 integrated circuit, and is certainly worth using if you happen to have one in your 'junk box'. The ZN415 includes an additional buffer stage which increases the output from the 30 to 60 millivolts produced by the ZN414E up to about 100 to 120 millivolts, enough to directly drive a pair of Walkman type headphones. The two 32 ohm earpieces must be arranged so that they are wired in series to give the necessary 64 ohm load. The ZN415 makes assembly even easier.

The ZN416E is similar to the ZN415E except that the output is raised still further to about 300 to 330 millivolts.



Circuit digram of the Ferranti ZN415 single chip radio. This circuit can also be used for the later higher output ZN416 and ZN416E integrated circuits - if you can find one.

The ZN415 / ZN416 / ZN416E is, like the ZN414, also discontinued by Ferranti, but you may be able to find one from somewhere, there may even be a replacement IC, but I have not come across one.

READER'S MK484 RADIOS:

Click HERE to see some MDS975 Reader's Radios >>

No AM radio stations or transmitters in your locality or country?

Has your local medium wave broadcast station closed or been moved to VHF/FM or Digital? Don't worry. You can still build and experiment with crystal sets and TRF radios by also buying or even building a simple low power AM transmitter. So, not only can you use your crystal sets but you can also run your own radio station that can be heard in and around your home - playing the music or programmes that you want to hear!

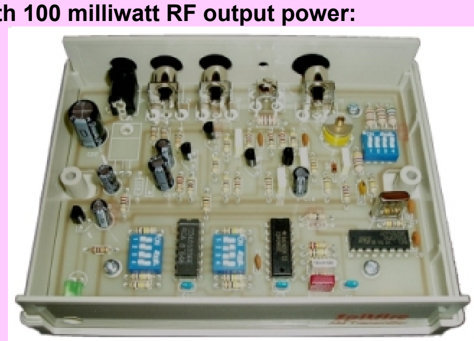
SSTRAN AMT3000 Superb high fidelity medium wave AM transmitter kits from SSTRAN. Versions available for 10kHz spacing in the Americas (AMT3000 or AMT3000-SM) and 9kHz spacing in Europe and other areas (AMT3000-9 and AMT3000-9SM). Superb audio quality and a great and well designed little kit to build: http://www.sstran.com/pages/products.html

http://www.sstran.com/

Other AM transmitters available:

Spitfire: Complete, high quality ready built medium wave AM Transmitters from Vintage Components: http://www.vcomp.co.uk/index.htm Vintage Components offer a choice of the high quality Spitfire and Metzo transmitters:

SPITFIRE AM Medium Wave Transmitter with 100 milliwatt RF output power:



http://www.vcomp.co.uk/spitfire/spitfire.htm

METZO AM Medium Wave Transmitter with built in compressor:

http://www.vcomp.co.uk/metzo/metzo.htm

AM88 LP A basic AM transmitter kit from North County Radio.
http://www.northcountryradio.com/Kitpages/am88.htm

RESISTOR COLOUR CODES
AND CAPACITOR CONVERSION TABLE >>>

Having difficulty in finding components? I have added some ideas for component sources here.
Sources For Older Components >>>

From Al:

Hi Mike,

I've read your site on and off for a few years now and finally got around to building a matchbox radio. I'd made one as a child during the '70s from the PW article, with the original Ferranti ZN414 and I'd always wanted to make another one to have, particularly so that I always had a mini radio to listen to the cricket on LW.

I did cheat slightly this time, as I ordered a kit (cheapest and not many people sell all the parts these days) and it came with a PCB board, my original was down on Vero-board. I will have to get some Vero-board so that I feel that I have made it 'properly'. I did wind my own aerial coil though.

What I find surprising, is that all the kits come with a AA battery holder, why do you want a huge battery on a mini radio when it will happily work off a soldered on button battery. The other thing is they all come with a mini on/off switch, what happened to have the earphone socket in line with the battery, so you switched it on by plugging the phones in.

Anyway, my reason for emailing you is the following. Rapid Electronics appear to be selling off their AM radio kits.They're selling them at £8.00 plus VAT (£9.60) for 5 kits. The kits don't include the PCB, which is about £3.00 (again, that's for 5 PCBs) and the tuning knob isn't included either (they say they've run out of them), but they have suitable knobs for sale that are about 25p each, it's a 6mm spindle on the tuning capacitor

I thought that it might be of interest to you or maybe the readers of your site, if you spend £20 plus VAT it's free delivery. It could be cheap radios for those that might want to put it together on a vero board and have tuning knobs lying about or rescued from old dead radios.

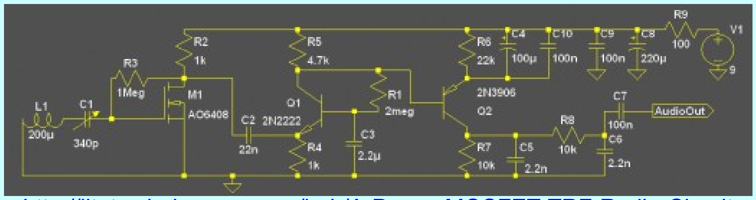
I've just ordered two packs (10 radio kits) with the PCBs and knobs and I'm going to start experimenting with them. I want a good working LW/MW/SW (individual radios), I'll go down the matchbox route and then afterwards see if I can buy a tidy project box that's about the same size. Then I want to see if I can have a combined MW/LW radio in a matchbox. I purchased a Maplin ready wound coil/ferrite rod for MW/LW and without the rod in the coil it picks up some MW stations, and then LW when the coil is inserted.

I have a feeling that my wife will probably disown me over the next few weeks, when I bore he rigid with how the projects are coming on.

Anyway, thanks for your informative website and all the best, Al.
April 2013

From Sean O'Connor:

Hi Mike, You might be interested in a Power MOSFET TRF circuit I have designed and built: http://litetec.hubpages.com/hub/A-Power-MOSFET-TRF-Radio-Circuit



http://litetec.hubpages.com/hub/A-Power-MOSFET-TRF-Radio-Circuit

Best Regards, Sean O'Connor

From Liz Costa:

Hi, MDS975 folk. I bought a MK484 from Maplin and didn't have a circuit for it so I entered the chip number into Google and I was taken directly to your site. You've given better and more detailed info on this than Maplin have and I certainly will be building the TRF soon. By the way I also LOVE pussycats. Yours are really gorgeous! Thanks for a great site!
Liz Costa 2E1FQN

From Dave Summer:

Hello Mike

An interesting site. I have made valve TRF radios since a boy in the 50's. I heard about 60 amateur countries on a two valve 1.4 volt set using AM. I know many hints and kinks about making these sets work. Another good circuit is to use a valve followed by a transistor. If you use a 6.3 volt mains valve, such as the 6AK5 or 6AM6, it can work perfectly OK with 6.3V HT as well, and is very sensitive. Of course, if you use an RF stage the set is isolated from the aerial, which is more steady in frequency. I find the 1.4 valves to be poor performers and prone to microphony.

If you want the set for short wave reception, you can use it in oscillating mode for CW, SSB and AM. In the case of AM, if you use a high anode load resistor, the circuit pulls-in slightly to the carrier. But if you do not like this, use a low resistor, then it does not. In practice, these two conditions are best obtained using a pentode with its screen acting as the oscillator anode. Use either a high screen dropper resistor, or a low resistance 5k potential divider for the screen depending if you want pull-in or not.

Modern valves are very high gain, and will work down to a few volts of HT. It is necessary to avoid too much regen'. A good way is to use a trimmer as the grid condenser, as a small capacitance of say 5 pF may be all that is needed. If you use a small grid condenser, you are in fact tapping the grid down the coil – it is an impedance matching action.

Always locate the grid condenser right at the grid, with a short lead; this prevents hum pick-up.

As for aerial coupling, the best way is via a small trimmer. In this way, the loading can be adjusted. A coupling coil is not so satisfactory and may introduce unwanted resonances and dead spots.

A resonant aerial is not desirable as it causes rapid changes in loading across the band. Choose a length such as a third of a wavelength.

If you want bandspread, a good method is to tap the bandspread capacitor down the coil, until it just gives the swing you want.

As far as hand-capacitance goes, this is a big problem and makes the use of traditional baseboard sets more or less useless. To avoid hand capacitance you must have the set in an enclosed metal box, and the phones lead must be decoupled.

RF chokes are a bit undesirable, but the Hartley oscillator (cathode tapped into the coil) avoids their use. Regen can usually be obtained using a resistor instead of a choke.

If you use an iron cored choke in the detector anode circuit, I believe the circuit will suffer from threshold howl.

If you use a battery valve, or you need more gain from a valve with very low HT, you can take the grid leak to a positive supply, either filament positive or HT. This increases gain but reduces overload capacity.

Finally, you cannot use a long wave ferrite rod in a set using a power audio IC, as the chip "radiates" noise in the long wave band which will be picked up by the rod, and the circuit will howl.

Finally, finally, although not TRF, a superb simple superhet can be made using a crystal controlled mixer ECH81 etc followed by an ordinary low frequency TRF.

I hope these things are of some interest!!

Dave

Click HERE to see some MDS975 Reader's Radios >>

T.R.F. RADIOS PART 2 >
The Ladybird Three Transistor Radio
The HAC "Heard All Continents Radio"

MORE TRF RADIOS - PART 3
Reader's Radios

TRF RADIOS - PART 4
Including The Medium Wave Mini

TRF RADIOS - PART 5

TRF RADIOS - PART 6

T.R.F. RADIOS PART 7

LINKS to Other Great Websites >

Visit my Amateur Radio Pages >

^Top Of Page

Home | **Contact** | **Site Map** | **Links** | **Thank You** | **Radio Stations & Memorabilia** | **Amateur Radio**

TRF RADIOS
Part 1
The ZN414 / MK484 I.C. & The Matchbox Radio

Having difficulty in finding components? I have added some ideas for component sources here.
Sources For Older Components LINKS to Other Great Websites

BUILD YOUR OWN MINIATURE 'MATCHBOX' RADIO

Worried About Soldering? Don't Be:

For some simple ideas on solderless construction techniques have a look at the Crystal Sets 2 and the Crystal Sets 5 pages. While the ultimate miniaturisation cannot be achieved with solderless techniques, it is still possible to produce a working project in this way. When constructing these small electronic projects it will be necessary to determine the exact value of resistors, which are colour coded, and capacitors, which sometimes have confusing numbers on them. I have included a table for both Resistor Colour Codes and a Capacitor Conversion Table HERE.

TRF RADIOS (Part 1)

INTRODUCTION

In the very early days of wireless a TRF (Tuned Radio Frequency) radio was the next step up from a crystal set. It offered amplification of both the radio frequency and the audio frequencies so that more stations could be received more strongly and the sounds produced would be amplified sufficiently to power a loudspeaker.

From the 1920' to the 1940's it was the glass *thermionic valve*, the forerunner to the transistor, that was the only component available for such amplification. A valve is quite a large device, about the size of an eggcup and looking a little like a small lightbulb. The valve needs its internal working parts , the anode and cathode, to be heated to operate (hence the term THERMionic) and so a valve contains filaments that glow red hot. Valve radios would consequently get quite warm and therefore

use quite a lot of power requiring several large batteries or mains power to operate. The valve filaments needing just a few volts to get hot, while the voltage required to obtain a flow of electrons in the anode would need 100 volts or more.

Later radios dispensed with the TRF technology in favour of the more sensitive and selective 'superhet' (supersonic heterodyne) method. If the set is in good working order the wireless listener will no doubt be rewarded with a wonderfully rich and warm sound quality. Many of these original valve sets had beautifully hand-crafted wooden cabinets which would often enclose a large loudspeaker that produced the fine sound quality.

Old mains valve radios can be very dangerous to dismantle and 'play around' with as they invariable have a live metal chassis. As this chassis will be at 230 volts mains potential the effect of a mis-positioned digit could be fatal, so I advise against this practice. Instead have a go at building a modern day TRF radio using the latest solid state (i.e. silicon transistors) technology, which operates at low power and with very low current consumption. It was not until the introduction of the transistor in the mid 1950's that radio sets could be made smaller and truly portable and consume much less power, making battery operation a practicality.

Building a TRF set today is quite straightforward as small transistors or IC's (Integrated Circuits containing several transistors and other components in a small sealed device) will require only battery power in the order of 1.5 to 6 or 9 volts to operate.

As mentioned a TRF radio has its limitations and was superceded by the *Superhet*, which is a principle used in all modern receivers, but the results achieved with modern components can be outstanding.

The TRF radios described here all use transistorized circuits, though some of the the circuit layouts are fairly similar to some early simple valve TRF radios.

BUILD A RADIO IN A MATCHBOX !

The rather battered magazine cover of Everyday Electronics
http://www.epemag3.com/

THE MATCHBOX RECEIVER

When my dad came home one night in the 1970's with a copy of Everyday Electronics magazine I was fascinated by an article describing how to home-build a radio so small that it would fit into a matchbox. I was a schoolboy taken with the hobby of radio and had recently built a regenerative radio described in the Ladybird book "Making A Transistor Radio". This book was given to

me as a birthday present from an aunt and the method of construction used was a simple solderless breadboard that trapped the component leads with number 6 brass wood screws and screw cups.

The Matchbox Receiver, on the other hand, required careful soldering of the components into a circuit board to achieve the small size needed to fit into a case as small as a matchbox. I did not have a soldering iron, I was too young.

Dad *did* have a soldering iron, it was not electric though and had to be heated over a gas flame! We spent several hours in the kitchen heating this big iron over the gas hob and soldering the tiny components onto the circuit board.

The matchbox receiver uses just two main components, one that I was familiar with - a transistor (the BC107), and a component new to me at the time, an Integrated Circuit (I.C.) containing no less than ten transistors inside a tiny TO-18 style can. The I.C. used is the Ferranti ZN414 which contains a high gain RF amplifier stage offering up to 72dB of gain, a detector stage and a.g.c. stage.

The ZN414 has a very high input impedance of around 4meg Ohms which minimizes any loading of the tuned circuit thereby improving selectivity, which is important when being used in a simple TRF radio such as is being described. The useable tuning range available from the ZN414 is from 150kHz (Long Wave) through Medium Wave and up to 3000kHz. Current consumption is tiny, making it very suitable for the matchbox radio powered by a silver-oxide button cell.

Once dad and I had soldered everything together and assembled the parts into a matchbox I think that we were both amazed that it worked! We received BBC Radio Four on 285 meters, Radio Three on 464 meters, Radio One on 247 meters, Radio Birmingham on 206 meters and BRMB Radio on 261 meters.

A Matchbox Radio
(This particular one uses the ZN415 IC - see the notes further down the page)

In 1975 the idea of being able to build a complete working radio that would fit inside an ordinary matchbox seemed absolutely amazing. Today it is run of the mill of course, but the article from Everyday Electronics of Sept 1975 is still really interesting.

As mentioned, it uses the Ferranti ZN414 integrated circuit which is no longer available, but the direct replacement MK484 can be used with confidence and is widely available from many outlets including [Bowood Electronics] , as are a ferrite rods, fixed capacitors, resistors, preset pots and 500pF trimmers. You may also have some similar and useful components in your junk box. The circuit could still be made up using a miniature tuning capacitor salvaged from a discarded Chinese pocket radio. See the alternative circuits too.

Another equivalent to the ZN414 and MK484 is, I am informed, the TA7642 which is available from Rapid Electronics.

I have now built a couple of these radios and another one using the ZN415 I.C. which includes an additional buffer stage of audio amplification.

So have a look at the article a little further down the page, I'm sure that you'll find it fascinating.

DID YOU KNOW?

Electronic component sizes are be effectively reduced by half every 18 months!
The same progress in design and manufacture enables computer processor (CPU) speeds to be doubled every 18 months.

This effect of miniaturization is quite noticeable even when working with the very ordinary components involved in the construction of this matchbox radio project, i.e. components with leads intended for use on an ordinary circuit board.

When I first built this radio in the late 1970's the resistors and capacitors were two or three times the size of the ones I used when re-building the project with current components. This helps greatly with construction inside a matchbox.

However this process of miniaturization has progressed beyond the 'ordinary' components that are used in everyday 'home-brew' projects, since there is a limit to how small such a component can be and remain usable on standard circuit boards. Today's powerful personal computers, laptops, mobile 'phones and digital cameras are all made possible by the use of very large scale integrated circuits and miniaturized 'surface mount' components such as resistors and capacitors that are the size of a pin head! These are rather more difficult to work with for the home constructor.

Photograph showing how components have been reduced in size as time has progressed
The top two are 0.01µF ceramic disc capacitors, the left one from the 1970's and the right one from 2003
The bottom two are resistors, the left one a 0.5 watt from the 1970's and the right one from 2003

BUILD A MATCHBOX RECEIVER !

THE EVERYDAY ELECTRONICS 'MATCHBOX RECEIVER' ARTICLE

MATCHBOX RECEIVER

BY F.G.RAYER

A miniature m.w. receiver using an integrated circuit to give good reception

A PORTABLE radio receiver able to give very good headphone reception from its internal ferrite aerial is nowadays quite easily constructed to fit inside a case the size of a matchbox due to miniaturisation of components. In fact the prototype receiver was fitted into an empty *matchbox*, assembly being in the tray and the outer part serving as a cover.

Tuning coverage is about 550 kilohertz to 1550 kilohertz, which is typical for the medium wave band.

CIRCUIT

The circuit diagram of the receiver is shown in Fig. 1. The ferrite aerial L1 forms a tunable parallel resonant circuit with compression trimmer C1. The output from this network (r.f.) is fed to integrated circuit IC1 which is a ZN414. This is a multistage amplifier and detector and processes the incoming modulated r.f. and extracts the audio signals making them available at the output lead. Resistor R1 is the necessary feedback resistor for IC1 and R2 and VR1 form the load for IC1.

The output from the integrated circuit is coupled, via C4, to audio amplifier TR1 which provides a considerable increase in volume.

Power is from a single 1.4V mercury battery. As there is no space for a conventional on/off switch, the output jack SK1 is so arranged that closure of the contacts B and C switches on the receiver. It is thus switched on by plugging in the headphones, and switched off by withdrawing the plug.

OUTPUT SOCKET

The output jack socket should be a switched type and can be 2·5mm or 3·5mm, but has to be

Components....

Resistors
R1 100kΩ
R2 470Ω
R3 680kΩ
All ¼W carbon ± 10%

SEE SHOP TALK

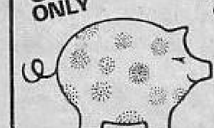
Capacitors
C1 450pF compression trimmer
C2 0·01μF plastic or ceramic
C3 0·1μF plastic or ceramic
C4 0·05μF plastic or ceramic

Semiconductors
IC1 ZN414 a.m. radio integrated circuit
TR1 BC107 silicon *npn*

Miscellaneous
VR1 1kΩ miniature carbon linear preset potentiometer
B1 MP675 1·4V mercury cell or similar
SK1 switched jack socket, 2·5mm or 3·5mm (see text)
Plain matrix board, 0·15in. 9 x 8 holes; ferrite-rod 37mm x 9mm (⅜in) diameter; 32 s.w.g. enamelled copper wire; knob (see text).

FOR GUIDANCE ONLY

ESTIMATED COST* OF COMPONENTS excluding V.A.T.



£2.40

*Based on prices prevailing at time of going to press

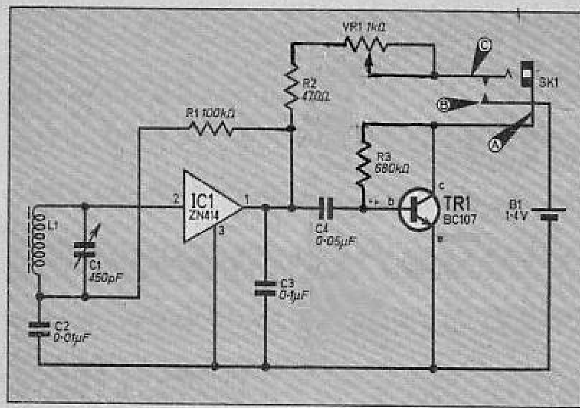


Fig. 1. Complete circuit diagram of the Matchbox Receiver

arranged so that the switchable contacts close when the plug is inserted. Jack sockets are normally made so that inserting the plug causes the contacts to open. If the required type is not readily available, the standard type should be modified. Some types of socket cannot be modified in this way so be alert when buying this component and inspect it to see if the modification can be carried out.

AERIAL AND TRIMMER

The winding L1 is 60 turns of 32 s.w.g. enamelled copper wire wound side by side on a ferrite rod 37mm long and 9mm ($^3/_8$in) in diameter. Winding should begin 3mm from one end of the rod, and the end turns secured with adhesive. (The whole winding should not be covered with adhesive.)

Trimmer C1 as supplied has an adjusting screw for setting by screwdriver. This should be replaced by a 6BA bolt (about 25mm long), taking care to retain the insulated and metal washers under its head. The bolt projects enough to take a 6BA lock-nut and knob or metal or insulated terminal head, see Fig. 3. This is for hand tuning.

The lock-nut is positioned so that the compression trimmer plates can spring fully open, or tuning coverage will be restricted and the high frequency end of the band cannot be reached.

COMPONENT BOARD

The prototype unit was built using 0·15 inch plain matrix board size 9 by 8 holes. The layout of the components on the board and the interconnecting wires on the underside of the board are shown in Fig. 2.

Begin by inserting a few components at a time, beginning with the resistors and capacitors and carrying out the underside wiring as you go along. Pay special attention to the lead-out connections when soldering IC1 in position and use a heatshunt on the leads when soldering; similarly with TR1.

Joints and leads should be flat against the board so as to avoid raising the board more than about a millimetre or so above the base of the matchbox tray when mounted in position. Sleeving is necessary on the lead on the underside from C3 to battery negative, see Fig. 2.

As the battery has a long life, connections are soldered directly to it; the case is the positive terminal. The ferrite rod assembly is secured to the component board with adhesive.

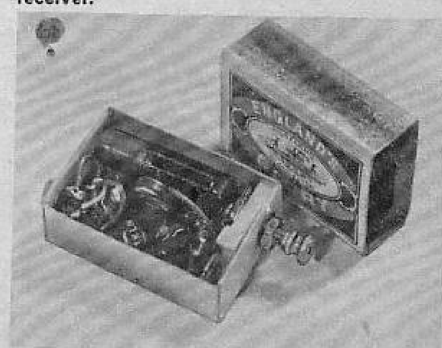
When all the board mounted components have been secured in position, SK1 and C1 should be wired in.

TESTING AND SETTING UP

Best results, and most comfortable listening, will be obtained with a complete headset, although a single minature earphone is of course

Continued on page 493

Photograph showing the construction of the receiver.



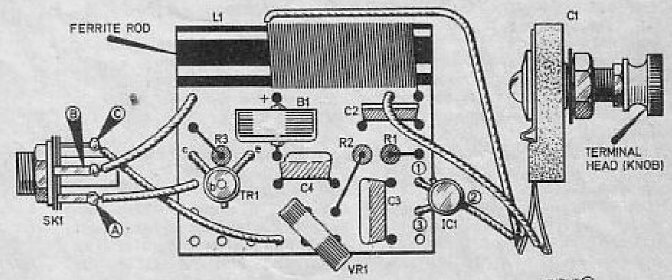
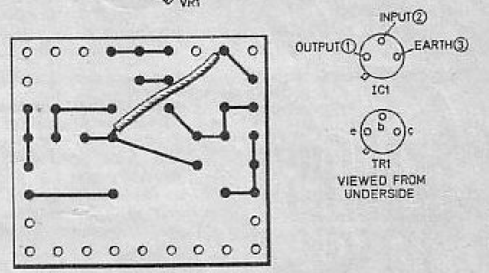


Fig. 2. Layout and wiring of the Matchbox Receiver.



Continued from page 485

easy to carry at other times. Medium or high impedance units, or headphones of about 2,000 ohms, are most suitable.

With the 'phones plugged in, adjusting C1 should tune in the stations which are best received in the locality. Some may be too loud, causing overloading, and this is corrected by turning the receiver to reduce signal pick up by the ferrite rod, if needed.

Potentiometer VR1 is adjusted with a small screwdriver. When VR1 is at a low value, or zero, volume is greatest, but oscillation may accompany some signals. If so, turn VR1 to increase resistance so that oscillation ceases. The setting is not critical. Later readjustment of VR1 will give some extra life for a failing battery.

All that remains to be done is fit the assembly into a matchbox—or other case if you desire—and the receiver is complete and ready for use.

Everyday Electronics, September 1975 493

New products and component buying for constructional projects

SHOP TALK

By Mike Kenward

Matchbox Receiver

Parts for the *Matchbox Receiver* must of course all be small —remember this point when buying the capacitors in particular. The output socket also acts as the on/off switch and must be of a particular type which is modified —see text.

The trimmer used for tuning can be modified to provide a tuning "knob" or a special conversion spindle can be purchased from Home Radio. The short piece of ferrite rod required is not likely to be sold as such and will have to be cut from a larger piece; do this by filing a notch around the rod at the required point and breaking off the section over the edge of a table.

http://www.epemag3.com/

Notes About Components On The Above Article:

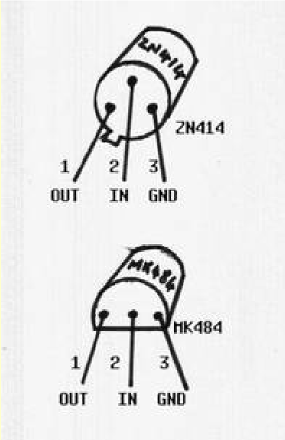
- **The ZN414 I.C. can be replaced with the current MK484 chip or the TA7642.**
- **The BC107 transistor can be replaced with a BC547, a BC182 or a ZTX300 (and other general purpose devices may work equally well).**
- **I found that the 680K biasing resistor could be replaced with a 470K or even a 100K without detriment.**
- **I used a 1.55 Volt Silver Oxide battery and found that the 1K preset potentiometer must be replaced with 10k preset pot to give an adequate range of control over gain.**
- **When using a Crystal Earphone a resistor of between 4.7k and 10k needs to be included from the collector of the BC107 to the positive rail (after the switched jack socket) i.e. across the earphone terminals. This will not effect the use of 1000 ohm earphones / earpieces.**

- **Also, have a look at the further information below for some more tips.**

SO GO AHEAD... GET BUILDING!

PARTS LIST

1 : MK484 (or TA7642 or ZN414) Integrated Circuit
1 : BC107 or BC547 or ZTX300 Transistor
1 : 500pF Miniature Postage Stamp Trimmer Capacitor
1 : Crystal (Ceramic) Earphone
1 : 0.01 µF Ceramic (or similar) Capacitor (103)
1 : 0.1 µF Ceramic (or similar) Capacitor (104)
1 : 0.047uF (0.05µF) Ceramic (or similar) Capacitor (473)
2: 100k Ohm ¼ watt Resistor



The Pin-Out Arrangement of the ZN414 and MK484 Integrated Circuits. The TA7642 is apparently the same as the MK484.

Try to avoid overheating the IC when soldering and keep the wiring of the whole circuit as neat as is possible to avoid unwanted oscillations that could occur with untidy wiring.

1 : 470 Ohm ¼ watt Resistor
1 : 4.7k Ohm ¼ watt Resistor (optional)
1 : 10k Miniature Preset Potentiometer
1 : 10mm Dia Ferrite Rod 100 or 150 mm long
1 : Reel of 0.5mm (approx) Enamelled Copper Wire
1 : 3.5 mm Jack Socket (for earphone)
1 : AA Battery Holder
1 : 1.5 Volt AA Battery
1 : On/Off Switch (optional)
1 : Tagboard or Verostrip board

BOWOOD ELECTRONICS
is a useful source for many of these components

You May Also Try:
J Birkett, The Strait, Lincoln for surplus items such as capacitors

Here are links to more component suppliers >>

AERIAL COIL DETAILS

MEDIUM WAVE: 60 to 65 Turns of 0.5 mm dia enamelled copper wire on a 10mm dia Ferrite Rod of about 35 to 40 mm long.

LONG WAVE: As above but with 250 turns of wire.

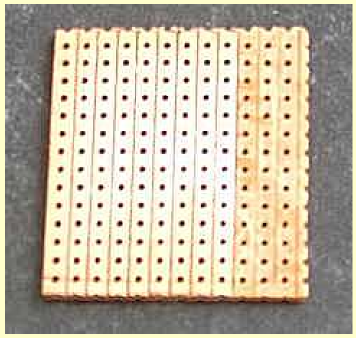
MY REBUILT MATCHBOX RECEIVER

My original matchbox receiver had got rather battered and worn, so being as I needed to solder a new battery into place I took the opportunity to refurbish the radio. I used the original Ferranti ZN414 i.c. , BC107 transistor and 500pF trimmer capacitor used for tuning. The resistors and capacitors I replaced with new smaller ones and I also replaced the circuit board and the 3.5mm jack socket with a new one as the original looked rather corroded. A 4.7k resistor was also included across the earphone output as I use these radios with a crystal earpiece, as mentioned above. I also replaced the medium wave coil with a Long Wave coil (purchased from Maplin Electronics) so that the radio could tune into 198 kHz for BBC Radio Four and also 252 kHz for RTÉ Radio One.

(I built another matchbox radio, using the newer MK484 i.c, and this covers Medium Wave. See further down this page. A TA7642 could also be used).

The photo above is a little trip through England's Glory matchbox history. The box top left is from 2004, and the box top right is probably from the 1990's while the box at the bottom is probably from the early 1980's. Incidentally England's Glory matches are now made in Sweden - so shouldn't they be called Sweden's Glory?

SCRAPE OFF THE VERO-STRIPS UNDERNEATH THE FERRITE-ROD AERIAL!



The photograph above shows the underside of the VeroStrip board that I used to build the matchbox radio. Note how three rows of copper strips have been removed using a sharp blade. The ferrite rod aerial sits above this area and leaving the copper in place reduces the "Q" (the effectiveness) of the tuned circuit very markedly.

Leaving the strips in place would result in poorer selectivity and sensitivity of the radio and thereby rather poor reception. I strongly recommend removing any strips from immediately below the ferrite rod aerial when constructing such a radio. Also keep the aerial away from any other metal objects that will mar the reception.

Above photo is a close up look at the re-built ZN414 matchbox radio with the new Long Wave tuning coil.

DON'T DESPAIR

Don't despair if you cannot find some of the components required for the Matchbox Receiver. The resistors will be no problem, of course, and can be 1/4 Watt, 1/2 Watt or 0.6 Watt at any tolerance. The capacitors can be Ceramic Disc, Resin Dipped Ceramic or Polyester and the values stated should not be varied for best performance.

As mentioned elsewhere the ZN414 is no longer available but the MK484 i.c. is widely and there should be no problem obtaining one of these. The TA7642 is another equivalent to the ZN414.

There will be no difficulty in finding a small piece of 10mm diameter ferrite rod and some 0.5mm dia, enamelled copper wire for the aerial.

There may be a little difficulty in finding the 500pF postage-stamp trimmer, and the 6BA brass screw and nut to extend the tuning shaft, but some careful searching should be rewarded with the necessary items.

Alternatives To The 500pF Trimmer For Tuning

Since components are so small these days, there will be an opportunity to use a miniature 200pF (approx) poly-dialectric (polyvaricon) tuning capacitor of the type that may be salvaged from a pocket transistor radio and that is generally more widely available from component suppliers. This would take up more space in the matchbox and the tuning knob would protrude from the back face of the box rather from one end. With careful re-arrangement of the components and some neat soldering there is a very good chance that everything could be still be accommodated in a matchbox, though I have not tried this yet.

Another alternative would be to have the matchbox receiver permanently tuned to a favourite station. The tuning circuit could then consist of a fixed capacitor of perhaps 50pF or 100pF or even a miniature trimming capacitor of similar value. The required favourite station could then be set by experimenting with the number of turns on the coil, and 'fine-tuned' with the small value trimmer, if that is what is used. This is just an idea but then the receiver would easily fit inside a matchbox.

The 3.5 jack socket has to be the open type, i.e. not enclosed in a plastic case, so that the switching operation can be changed from opening when the earphone plug is inserted, to closing when the plug is inserted. A pair of pointed nose pliers is all that is required to bend the switching contacts into the required position.

ANOTHER OF MY MATCHBOX RADIOS

This One Using The MK484 IC

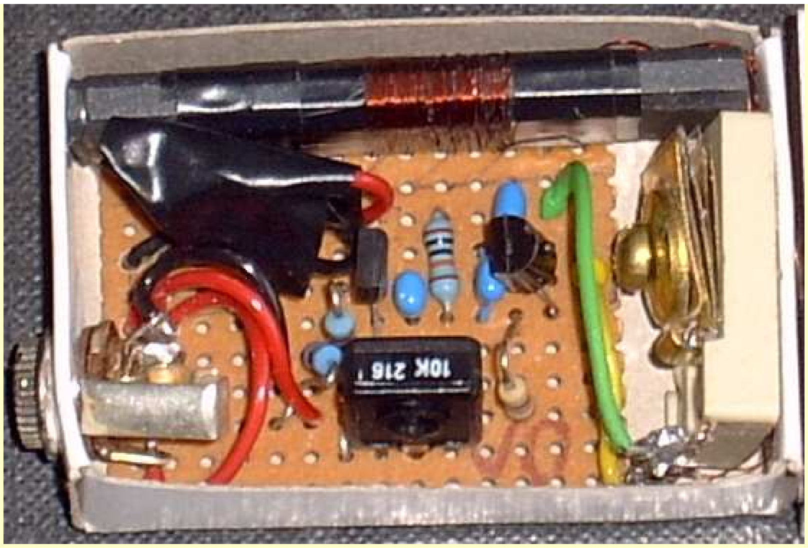
I have recently built another matchbox receiver, which is shown above and uses the MK484, a replacement for the ZN414. This radio uses a ZTX300 transistor as the audio output device which, in this case, has a 100K biasing resistor, rather than the 680K resistor specified in the Everyday Electronics magazine article above. In fact a BC107, a ZTX300 or a BC547 transistor can be used in this circuit, with a 100k biasing resistor all with equally good results.

I strongly recommend using a crystal earphone rather than the high impedance magnetic earphone referred to in the article since such earphones are almost impossible to come by. My own Matchbox radio will drive a pair of 32 Ohm 'Walkman' type headphones to reasonable volume when the two earpieces are wired in SERIES to provide a 64 Ohm load, but a crystal earphone is much MUCH louder which means that more of the weaker stations can be heard.

I therefore recommend the use a crystal earphone, however a 4.7K Ohm resistor (up to about 10K works) needs to be soldered across the earphone output; i.e. between the collector of TR1 (the BC107, BC547 or ZTX300) and the positive (+ve) rail - before the preset potentiometer and after the on/off switch (or switched jack socket if that method of switching is employed, as it is in my radio).

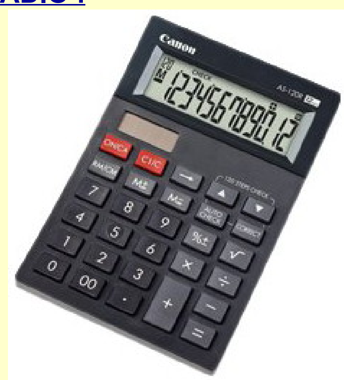
I would also recommend the use of a 10k preset potentiometer to set the gain, as my radio was far too loud and rather distorted when using a new 1.55 volt silver oxide button cell and even a 4.7K preset potentiometer could not introduce enough resistance into the circuit to sufficiently reduce the gain. The 10K pot works very well in my set.

As with all these designs don't forget to scrape off the copper strips from the Veroboard below the area where the ferrite rod aerial will be mounted. Failure to remove these strips will not prevent the radio from working, but the performance of the tuned circuit will be marred.



Photograph showing a close-up of the inside of my Matchbox Radio
The tiny silver oxide battery is covered in black insulating tape.
The skeletal jack socket has been modified so that the contacts make a circuit when inserting the earphone jack plug rather than breaking the circuit as is usually the case.
This then automatically switches the radio on when the earphone is plugged in.

SOLAR POWERED MK484 MATCHBOX RADIO !



Solar Power !

Hi Mike,

I was very pleased to read about the ZN414 Matchbox radio and its variants (MK484 & TDA7642) as I have experimented with it before. Readers might be interested in the fact that this little radio can even be driven using an old solar panel salvaged from a pocket calculator! These panels usually provide up to 2 Volts being exposed to bright daylight and a current of 1mA or more.

If you are worried about voltage overload simply add a 1.5 V zener diode or a rechargeable button cell in parallel which will cut down Voltage, thus protecting your precious ZN414 and avoiding self oscillating.

With best regards from Germany, Dietmar DH7AMQ [April 2013]

Thanks Dietmar - What an excellent idea!

SOME ALTERNATIVE MK484 (ZN414) (TA7642) CIRCUITS
(Which Also Work Really Well!)

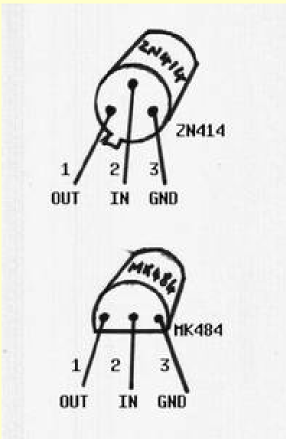
Even simpler than the 'Matchbox Radio' described in the above 1975 Everyday Electronics article would be to use the circuit below which omits the amplification (BC107 transistor) stage. The ZN414, TA7642 or MK484 is still able to drive a simple Crystal earpiece to reasonable volume, though obviously not as loud as with the additional transistor included. This approach would make it even easier to assemble the receiver into a matchbox. I have also constructed this set (though not inside a matchbox) and it works brilliantly with a simple crystal earpiece. I decided to use a 4 inch (10cm) long ferrite rod, which produces better signal pick-up so that stations will be more clearly heard.

The aerial coil consists of 60 turns of 0.56mm diameter enamelled copper wire which gives good coverage of the Medium Wave band even when using a small 220 pF tuning capacitor. Battery power is again only 1.5 volts, this time I used a penlight AA cell which will last for a very very long time indeed. The 10k Ohm preset pot sets the internal gain of the MK484 integrated circuit and while not critical in many cases careful adjustment is needed in strong signal areas to help prevent overloading.

Keep construction of the circuit very neat with component leads as short as is practicable. Ideally the radio should be built on a

small piece of VeroStrip, but if you wish to experiment with components and values then an ordinary piece of tag-board will be quite suitable. A 6 x 6 tag board will be more than adequate for this circuit and I have built these sets in this way very successfully, but bear in mind to keep the output components and battery away from the coil and tuning capacitor.

Other component values should be adhered to to obtain best results, the 0.1uF capacitor at Pin 1 (output) of the MK484, the 100k Ohm resistor and the 470 Ohm resistor should not really be changed. The 0.01µF capacitor can be experimented with and could be between 0.01 and 0.0068 µF. The 0.05µF output de-coupling capacitor is not too critical and the resistor across the crystal earpiece could be 2.7K Ohm 4.7K, 6.8K perhaps up to 10K depending on the particular earphone used. I found that a 2.7K resistor allows my crystal earphone to work very effectively indeed. The battery voltage should not be changed and should be between 1.4 and 1.6 volts. Either an original Ferranti ZN414 IC or the later MK484 IC can be used in these circuits, the newer MK484 may work even better than the excellent, but now obsolete, ZN414.



The Pin-Out Arrangement of the ZN414 and MK484 (TA7642) Integrated Circuits.

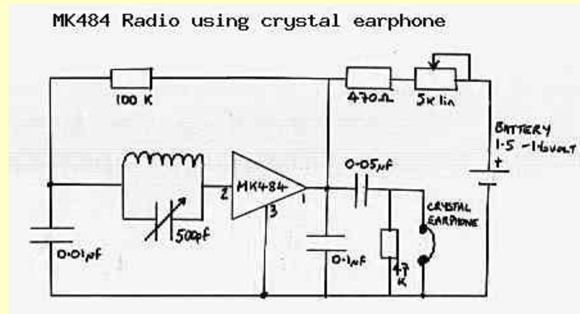
Try to avoid overheating the IC when soldering and keep the wiring of the whole circuit as neat as is possible to avoid unwanted oscillations that could occur with untidy wiring.

AERIAL COIL DETAILS

MEDIUM WAVE: 60 Turns of 0.5 mm dia enamelled copper wire on a 10mm dia Ferrite Rod of between 100 and 150 mm long

LONG WAVE: As above but with 250 turns of wire with the coil ideally being shunted with a 220k Ohm resistor

Maplin Electronics have been selling a 10mm diameter ferrite rod with a pre-wound medium wave and long wave coil included and this may provide another option. Ferrite rods are also available from Bowood Electronics.



+ See note below

PARTS LIST

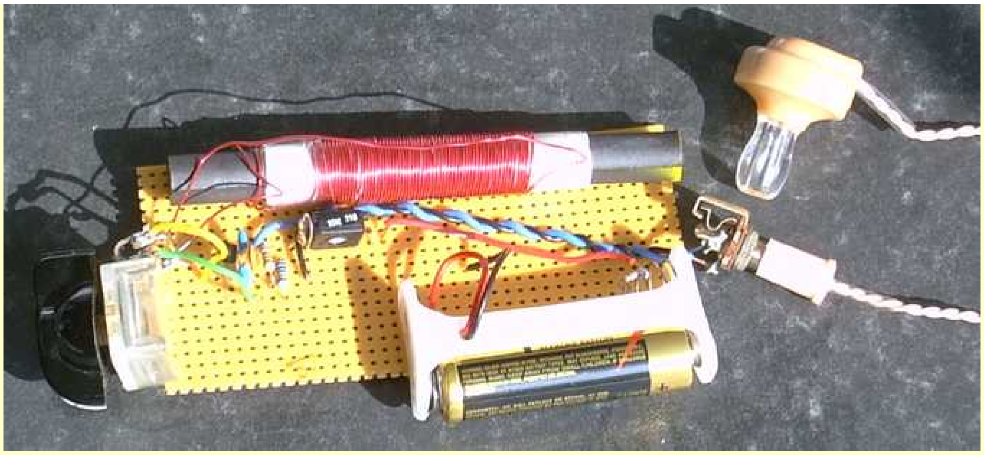
1 : MK484 (or TA7642 or ZN414) Integrated Circuit
1 : 220pF or 500pF Tuning Capacitor
1 : Crystal (Ceramic) Earphone
1 : 0.01 µF Ceramic (or similar) Capacitor (103)
1 : 0.1 µF Ceramic (or similar) Capacitor (104)
1 : 0.047uF (0.05µF) Ceramic (or similar) Capacitor (473)
1 : 100k Ohm ¼ watt Resistor
1 : 470 Ohm ¼ watt Resitor
1 : 2.7k (or 4.7k) Ohm ¼ watt Resistor
1 : 10k Preset Potentiometer
1 : 10mm Dia Ferrite Rod 100 or 150 mm long
1 : Reel of 0.5mm (approx) Enamelled Copper Wire
1 : 3.5 mm Jack Socket (for earphone)
1 : AA Battery Holder
1 : 1.5 Volt AA Battery
1 : On/Off Switch (optional)
1 : Tagboard or Verostrip board

BOWOOD ELECTRONICS
is a useful source for many of these components

You May Also Try:
J Birkett, The Strait, Lincoln for surplus items such as capacitors

Here are links to more component suppliers >>

+ Our correspondent Chas Castagana, in the USA, had some trouble with this circuit he writes: I constructed this circuit as close to your spec's as I could, ...perhaps it may be better to feed the output into an external transistor amplifier stage.
I think Chas may have been using headphones which possibly may not work as well as a Crystal Earphone that I had intended.
This design can certainly be fed into a discrete transistor amplifier stage and will give excellent results in this way, but even connecting the crystal earphone between the output and ground (as shown) I find that there is a more than usable audio output on all local stations. It is worth including the circuit here due to its simplicity and good performance. it may also be worth experimenting with connecting the crystal earphone between the output, via 0.05 uF capacitor, and the positive rail (i.e. to the positive side of the battery) and connecting the 47k Ohm resistor across the earphone output. Either way I don't think constructors will be disappointed. Thanks Chas for the input!

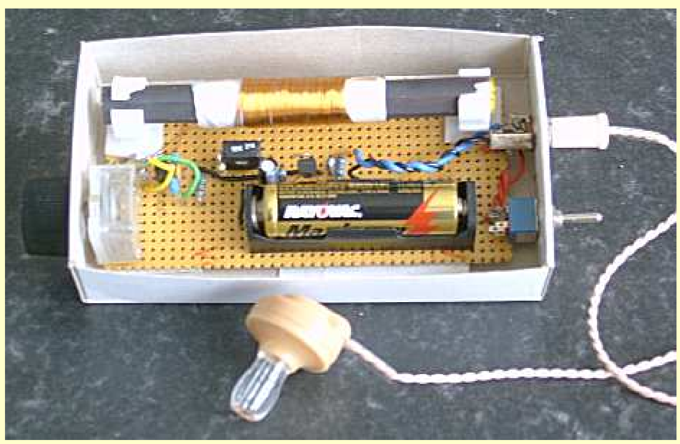


The Working Single Chip MK484 Radio Constructed On A Piece Of VeroStrip

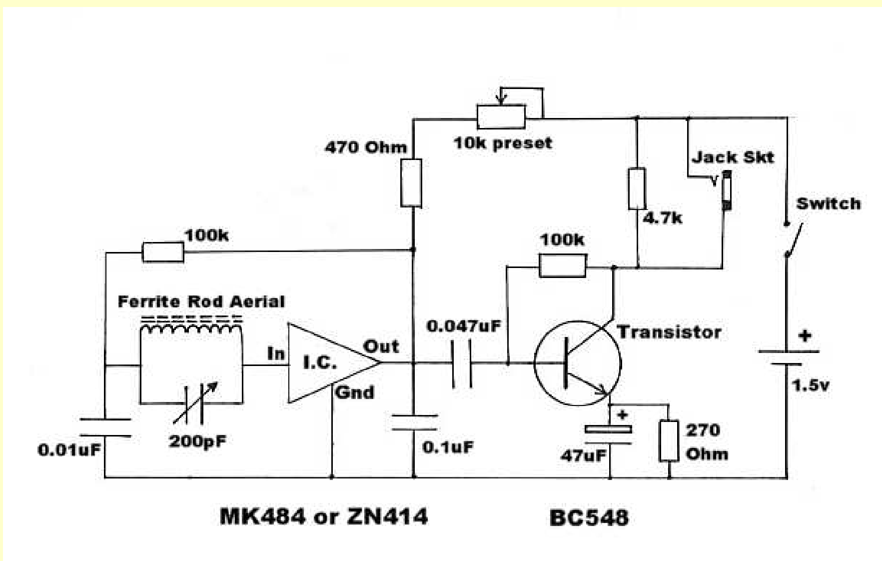
At our location I can receive the three national stations, BBC Radio Five Live, Talk Sport and Absolute (Virgin) Radio from a main transmitter about 25-30 miles away plus BBC Five Live from a main transmitter about 80 miles away on 909 kHz. Two low power local stations (990 kHz 0.1 kW and 828 kHz 0.2 kW) are also received at good strength from their transmitters located 6 miles away. Before it closed, a community station on 1350 kHz at only 0.001kW located about 4 miles away could also be received. Additionally three other local radio transmitters (3 to 6 kW) about 15-20 miles away were also receivable. At night a number of other broadcasts can be heard easily, e.g. 1440 from Luxembourg and 1512 kHz from Belgium and some others such as 567 kHz from Eire and 675 kHz from The Netherlands.

ADDITIONAL AUDIO AMPLIFICATION USING THE BC548 TRANSISTOR

The MK484 receiver shown below uses a BC548 transistor as the audio output stage. It also uses a larger ferrite rod aerial for better signal pick-up, a standard "AA" battery cell and a widely available miniature polyvaricon tuning capacitor of approximately 200pF for ease of construction. This really is a superb radio!



Above the completed "Cook's Matchbox Radio"
Housed in a larger matchbox to accommodate a longer ferrite rod aerial for improved pick-up and a standard "AA" battery cell together with the more orthodox polyvaricon type tuning capacitor. The larger housing also makes construction a little easier.
See the circuit diagram for this radio below:



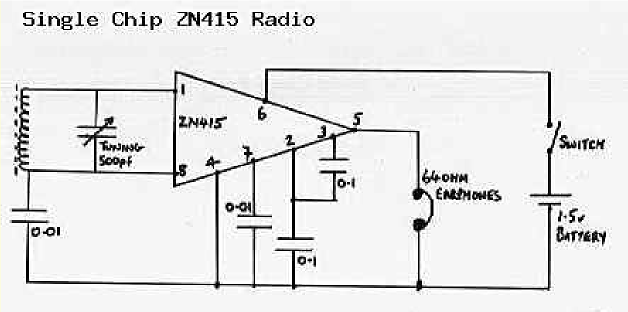
Above: Circuit Diagram For The Excellent MK484 (or TA7642 or ZN414) with the BC548 transistor stage of amplification.

The tuning capacitor can be any standard type of between about 200pF and 500pF and the polyvaricon type commonly found in pocket radios and should be available new from many component suppliers.
A crystal earpiece should be used, although excellent results may be obtained with a pair of good quality and sensitive 32 Ohm 'Walkman' type headphones. If these earphones are to be used, the 32 Ohm earpieces must be wired in SERIES so that the total load is 64 Ohms. This can be arranged by using a stereo jack socket and connecting the output across the first two (small) rings of the headphone plug and making no connection to the upper (longer) part of the plug which is the common/ground connection of the 'phones.

THE ZN415E and ZN416E

Have a look at the circuit below which uses the ZN415 integrated circuit, and is certainly worth using if you happen to have one in your 'junk box'. The ZN415 includes an additional buffer stage which increases the output from the 30 to 60 millivolts produced by the ZN414E up to about 100 to 120 millivolts, enough to directly drive a pair of Walkman type headphones. The two 32 ohm earpieces must be arranged so that they are wired in series to give the necessary 64 ohm load. The ZN415 makes assembly even easier.

The ZN416E is similar to the ZN415E except that the output is raised still further to about 300 to 330 millivolts.



Circuit digram of the Ferranti ZN415 single chip radio. This circuit can also be used for the later higher output ZN416 and ZN416E integrated circuits - if you can find one.

The ZN415 / ZN416 / ZN416E is, like the ZN414, also discontinued by Ferranti, but you may be able to find one from somewhere, there may even be a replacement IC, but I have not come across one.

READER'S MK484 RADIOS:

Click HERE to see some MDS975 Reader's Radios >>

No AM radio stations or transmitters in your locality or country?

Has your local medium wave broadcast station closed or been moved to VHF/FM or Digital? Don't worry. You can still build and experiment with crystal sets and TRF radios by also buying or even building a simple low power AM transmitter. So, not only can you use your crystal sets but you can also run your own radio station that can be heard in and around your home - playing the music or programmes that you want to hear!

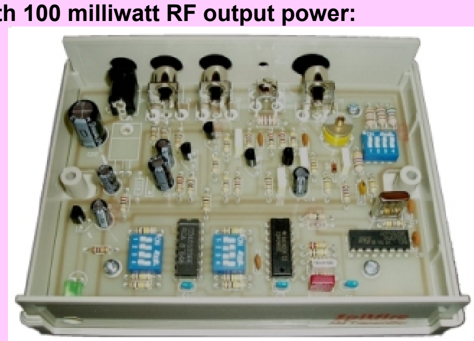
SSTRAN AMT3000 Superb high fidelity medium wave AM transmitter kits from SSTRAN. Versions available for 10kHz spacing in the Americas (AMT3000 or AMT3000-SM) and 9kHz spacing in Europe and other areas (AMT3000-9 and AMT3000-9SM). Superb audio quality and a great and well designed little kit to build: http://www.sstran.com/pages/products.html

http://www.sstran.com/

Other AM transmitters available:

Spitfire: Complete, high quality ready built medium wave AM Transmitters from Vintage Components: http://www.vcomp.co.uk/index.htm Vintage Components offer a choice of the high quality Spitfire and Metzo transmitters:

SPITFIRE AM Medium Wave Transmitter with 100 milliwatt RF output power:



http://www.vcomp.co.uk/spitfire/spitfire.htm

METZO AM Medium Wave Transmitter with built in compressor:

http://www.vcomp.co.uk/metzo/metzo.htm

AM88 LP A basic AM transmitter kit from North County Radio.
http://www.northcountryradio.com/Kitpages/am88.htm

RESISTOR COLOUR CODES
AND CAPACITOR CONVERSION TABLE >>>

Having difficulty in finding components? I have added some ideas for component sources here.
Sources For Older Components >>>

From Al:

Hi Mike,

I've read your site on and off for a few years now and finally got around to building a matchbox radio. I'd made one as a child during the '70s from the PW article, with the original Ferranti ZN414 and I'd always wanted to make another one to have, particularly so that I always had a mini radio to listen to the cricket on LW.

I did cheat slightly this time, as I ordered a kit (cheapest and not many people sell all the parts these days) and it came with a PCB board, my original was down on Vero-board. I will have to get some Vero-board so that I feel that I have made it 'properly'. I did wind my own aerial coil though.

What I find surprising, is that all the kits come with a AA battery holder, why do you want a huge battery on a mini radio when it will happily work off a soldered on button battery. The other thing is they all come with a mini on/off switch, what happened to have the earphone socket in line with the battery, so you switched it on by plugging the phones in.

Anyway, my reason for emailing you is the following. Rapid Electronics appear to be selling off their AM radio kits.They're selling them at £8.00 plus VAT (£9.60) for 5 kits. The kits don't include the PCB, which is about £3.00 (again, that's for 5 PCBs) and the tuning knob isn't included either (they say they've run out of them), but they have suitable knobs for sale that are about 25p each, it's a 6mm spindle on the tuning capacitor

I thought that it might be of interest to you or maybe the readers of your site, if you spend £20 plus VAT it's free delivery. It could be cheap radios for those that might want to put it together on a vero board and have tuning knobs lying about or rescued from old dead radios.

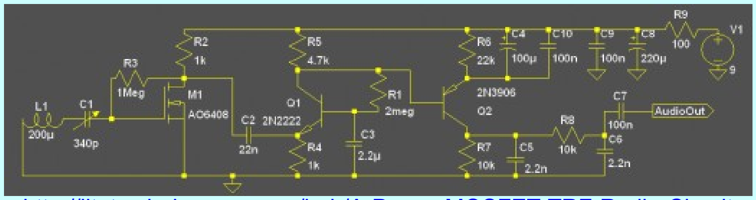
I've just ordered two packs (10 radio kits) with the PCBs and knobs and I'm going to start experimenting with them. I want a good working LW/MW/SW (individual radios), I'll go down the matchbox route and then afterwards see if I can buy a tidy project box that's about the same size. Then I want to see if I can have a combined MW/LW radio in a matchbox. I purchased a Maplin ready wound coil/ferrite rod for MW/LW and without the rod in the coil it picks up some MW stations, and then LW when the coil is inserted.

I have a feeling that my wife will probably disown me over the next few weeks, when I bore he rigid with how the projects are coming on.

Anyway, thanks for your informative website and all the best, Al.
April 2013

From Sean O'Connor:

Hi Mike, You might be interested in a Power MOSFET TRF circuit I have designed and built: http://litetec.hubpages.com/hub/A-Power-MOSFET-TRF-Radio-Circuit



http://litetec.hubpages.com/hub/A-Power-MOSFET-TRF-Radio-Circuit

Best Regards, Sean O'Connor

From Liz Costa:

Hi, MDS975 folk. I bought a MK484 from Maplin and didn't have a circuit for it so I entered the chip number into Google and I was taken directly to your site. You've given better and more detailed info on this than Maplin have and I certainly will be building the TRF soon. By the way I also LOVE pussycats. Yours are really gorgeous! Thanks for a great site!
Liz Costa 2E1FQN

From Dave Summer:

Hello Mike

An interesting site. I have made valve TRF radios since a boy in the 50's. I heard about 60 amateur countries on a two valve 1.4 volt set using AM. I know many hints and kinks about making these sets work. Another good circuit is to use a valve followed by a transistor. If you use a 6.3 volt mains valve, such as the 6AK5 or 6AM6, it can work perfectly OK with 6.3V HT as well, and is very sensitive. Of course, if you use an RF stage the set is isolated from the aerial, which is more steady in frequency. I find the 1.4 valves to be poor performers and prone to microphony.

If you want the set for short wave reception, you can use it in oscillating mode for CW, SSB and AM. In the case of AM, if you use a high anode load resistor, the circuit pulls-in slightly to the carrier. But if you do not like this, use a low resistor, then it does not. In practice, these two conditions are best obtained using a pentode with its screen acting as the oscillator anode. Use either a high screen dropper resistor, or a low resistance 5k potential divider for the screen depending if you want pull-in or not.

Modern valves are very high gain, and will work down to a few volts of HT. It is necessary to avoid too much regen'. A good way is to use a trimmer as the grid condenser, as a small capacitance of say 5 pF may be all that is needed. If you use a small grid condenser, you are in fact tapping the grid down the coil – it is an impedance matching action.

Always locate the grid condenser right at the grid, with a short lead; this prevents hum pick-up.

As for aerial coupling, the best way is via a small trimmer. In this way, the loading can be adjusted. A coupling coil is not so satisfactory and may introduce unwanted resonances and dead spots.

A resonant aerial is not desirable as it causes rapid changes in loading across the band. Choose a length such as a third of a wavelength.

If you want bandspread, a good method is to tap the bandspread capacitor down the coil, until it just gives the swing you want.

As far as hand-capacitance goes, this is a big problem and makes the use of traditional baseboard sets more or less useless. To avoid hand capacitance you must have the set in an enclosed metal box, and the phones lead must be decoupled.

RF chokes are a bit undesirable, but the Hartley oscillator (cathode tapped into the coil) avoids their use. Regen can usually be obtained using a resistor instead of a choke.

If you use an iron cored choke in the detector anode circuit, I believe the circuit will suffer from threshold howl.

If you use a battery valve, or you need more gain from a valve with very low HT, you can take the grid leak to a positive supply, either filament positive or HT. This increases gain but reduces overload capacity.

Finally, you cannot use a long wave ferrite rod in a set using a power audio IC, as the chip "radiates" noise in the long wave band which will be picked up by the rod, and the circuit will howl.

Finally, finally, although not TRF, a superb simple superhet can be made using a crystal controlled mixer ECH81 etc followed by an ordinary low frequency TRF.

I hope these things are of some interest!!

Dave

Click HERE to see some MDS975 Reader's Radios >>

T.R.F. RADIOS PART 2 >
The Ladybird Three Transistor Radio
The HAC "Heard All Continents Radio"

MORE TRF RADIOS - PART 3
Reader's Radios

TRF RADIOS - PART 4
Including The Medium Wave Mini

TRF RADIOS - PART 5

TRF RADIOS - PART 6

T.R.F. RADIOS PART 7

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DIY Audio Home

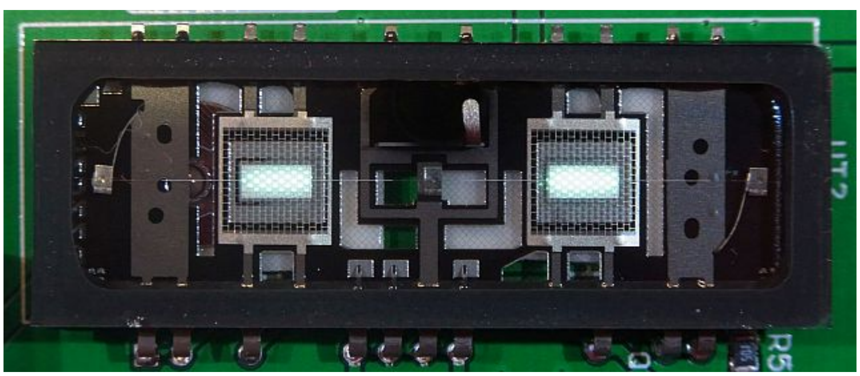
The "NuHybrid" Headphone Amp - Hybrid headphone amp using the Korg Nutube

(Note most photos are hyperlinked to full resolution photos).

I've made some updates to the Mouser BOM due to a few items being out of stock for an extended period. The power switch, and two electrolytic capacitors, have been swapped for parts that are compatible and in stock (at least as of today).

This is a hybrid headphone amplifier that uses the Korg Nutube 6P1. It's based somewhat on the original "Millett hybrid" design that I published way back in 2002.

Like the original, this one can be built as an open PCB, mounted into a plastic base, with the parts (and glowing Nutube) exposed for all to see. Of course, you could also package it in a normal case if you wanted to. Also like the original, it uses a low-voltage tube stage to do the voltage amplification, and solid-state circuitry (this time an OPA551 opamp connected as a follower) to drive the current into the headphones.



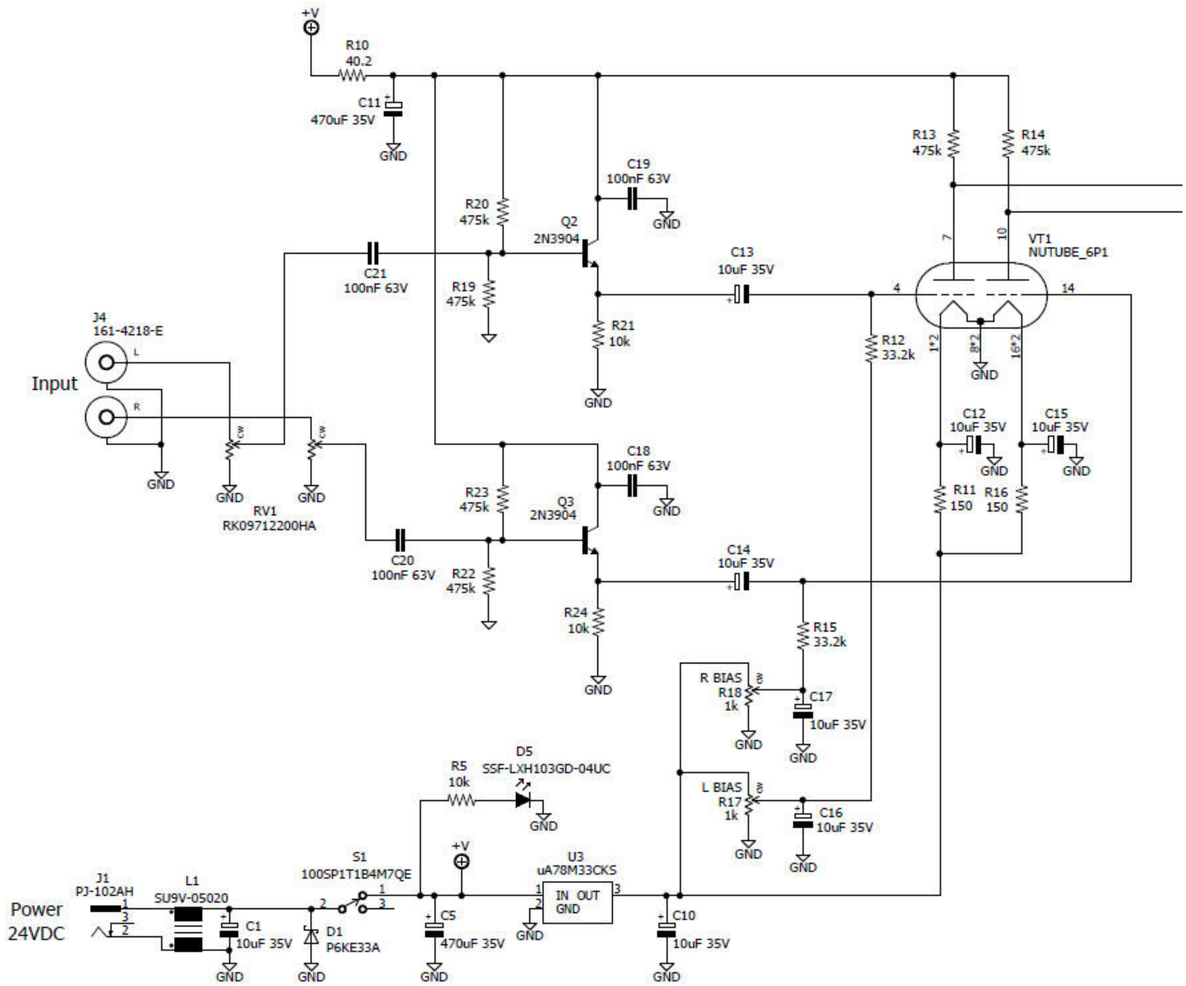
The tube used here is the new Korg Nutube 6P1. The Nutube is a dual, very low power, directly-heated triode tube. It is built using a process originally used for Vacuum Fluorescent Displays (VFDs) - that is why you can see a bluish-white glow when the tube is powered up. I've been working with the folks at Korg in Japan for a while with this part, and use it in the Apex Sangaku headphone amplifier. I also arranged with Korg to distribute the 6P1 to DIYers and small OEMs. To that end I created www.nutube.us. You can find additional info on the 65P1 there, including the full datasheet.

The entire thing, including power supply, knob, etc. will cost you about $116. I am basically giving away the PCB for free with a Nutube in order to try and generate some interest in it.

Like the DIY Butte headphone amp, I want this to be a very easy project for somebody who has little electronics experience. To make it as easy as possible, I put together a comprehensive instruction manual, as well as a BOM (parts list) on Mouser's website, so it makes ordering the parts simple. More on that a bit further down the page...

The Circuit

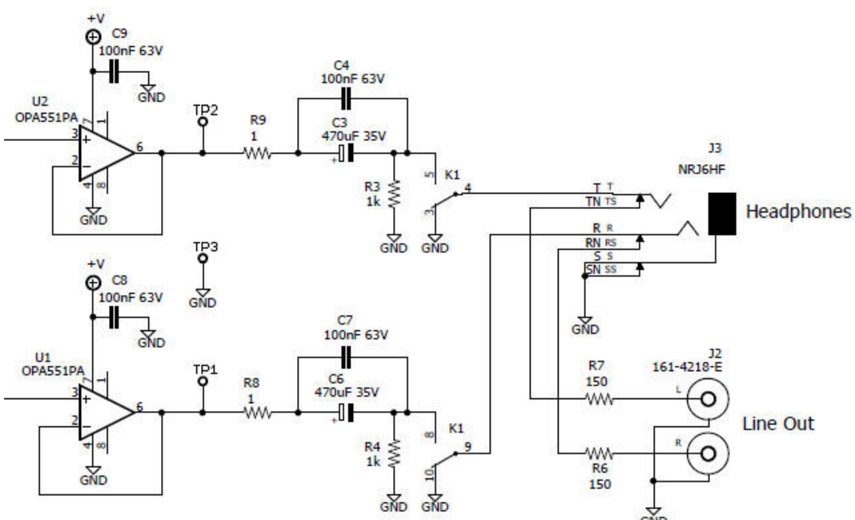
(Download a full size schematic in PDF form)



The input signal comes from RCA jacks, through a volume control pot, and is capacitively coupled into a pair of MOSFET followers using 2N7002 FETs. This is needed because the Nutube 6P1 is operated in "class A2" - that is, the control grid is biased slightly positive, so the grid draws a little bit of current when driven. The output of the buffer is coupled using a 10uF capacitor into the Nutube grids. A positive grid bias of 0V to 3.3V, adjustable using trimpots, is applied to the grids through a 33k resistor.

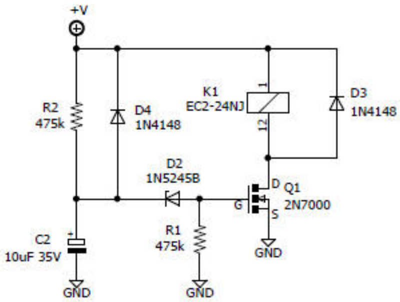
Filament power - which is only 700mV at 17mA per triode - is supplied via 150 ohm dropping resistors from a 3.3V linear regulator (which also supplies the positive grid bias).

24V is supplied by a standard wall adapter. The plates of the Nutube are loaded with 475k resistors to the positive supply, which is a filtered (by R10 & C11) version of the 24V input.



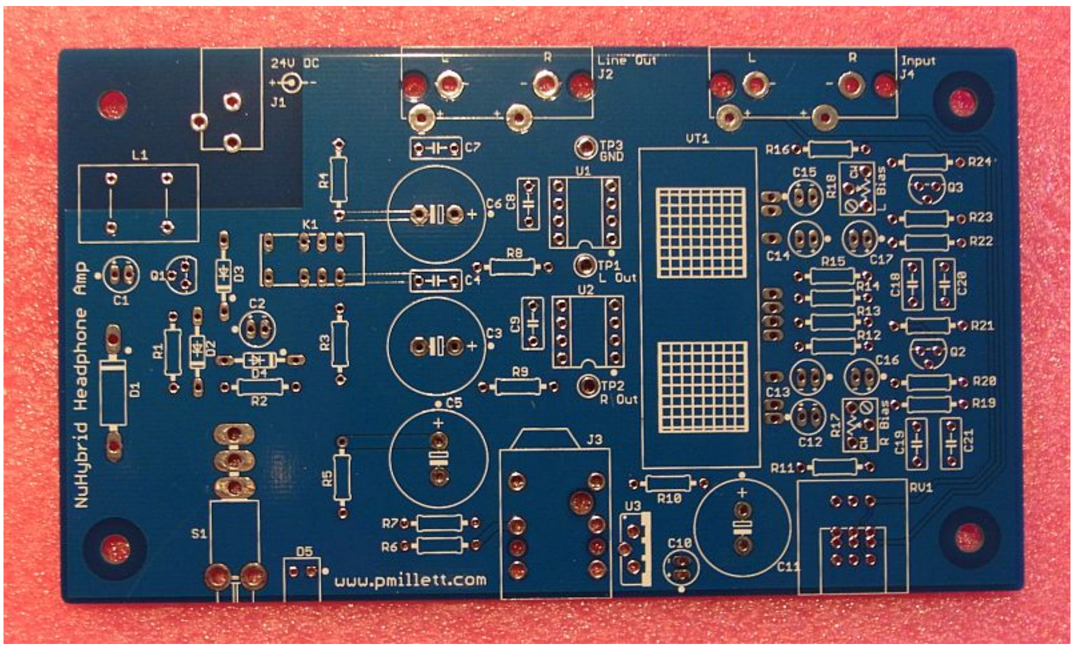
The plates of the Nutube are directly coupled to a pair of opamp buffers. I used the OPA551 here, because I've had good success using it. Others will work, including the BUF634 open-loop buffer. I found that the OPA551 gave better performance, especially in that it contributed very little high-order harmonic distortion. The opamp

output is capacitively coupled to the headphone jack through some large electrolytic capacitors (bypassed with small film caps). In addition, a pair or RCA jacks can be used to get a line output, for use as a preamp.

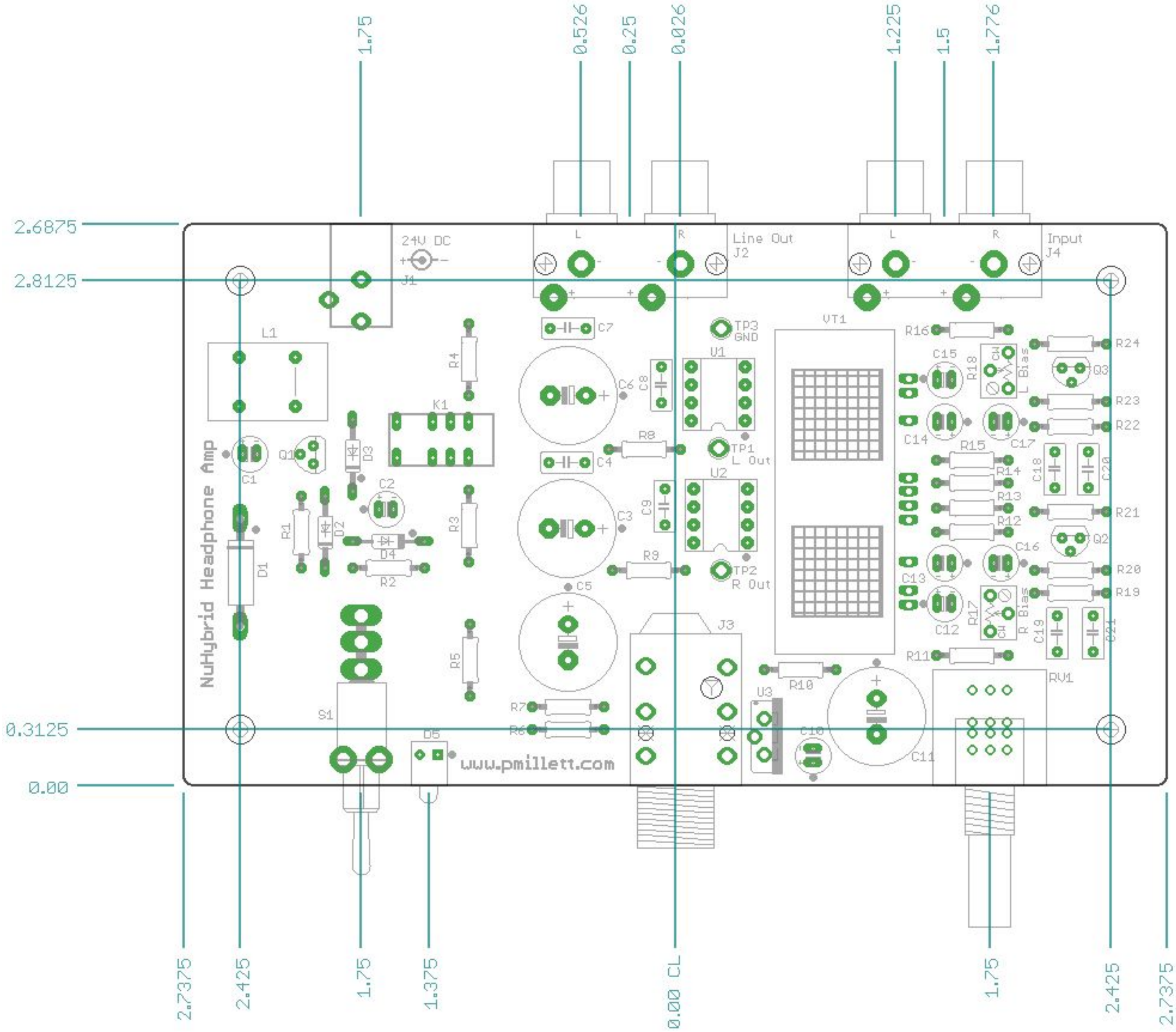


One addition that is not in the original Millett hybrid is the inclusion of an output muting circuit. This keeps the output disabled for about ten seconds after power-up, eliminating the big "thump" that you would otherwise hear as the output capacitors charged. This circuit is a simple MOSFET to drive the relay coil, and some diodes and an RC circuit on the gate. When the power is turned on, the capacitor on the gate is slowly charged until the gate voltage gets high enough to turn on the MOSFET, which pulls in the relay. When power is turned off, a diode quickly discharges the cap and drops the relay.

The PCB

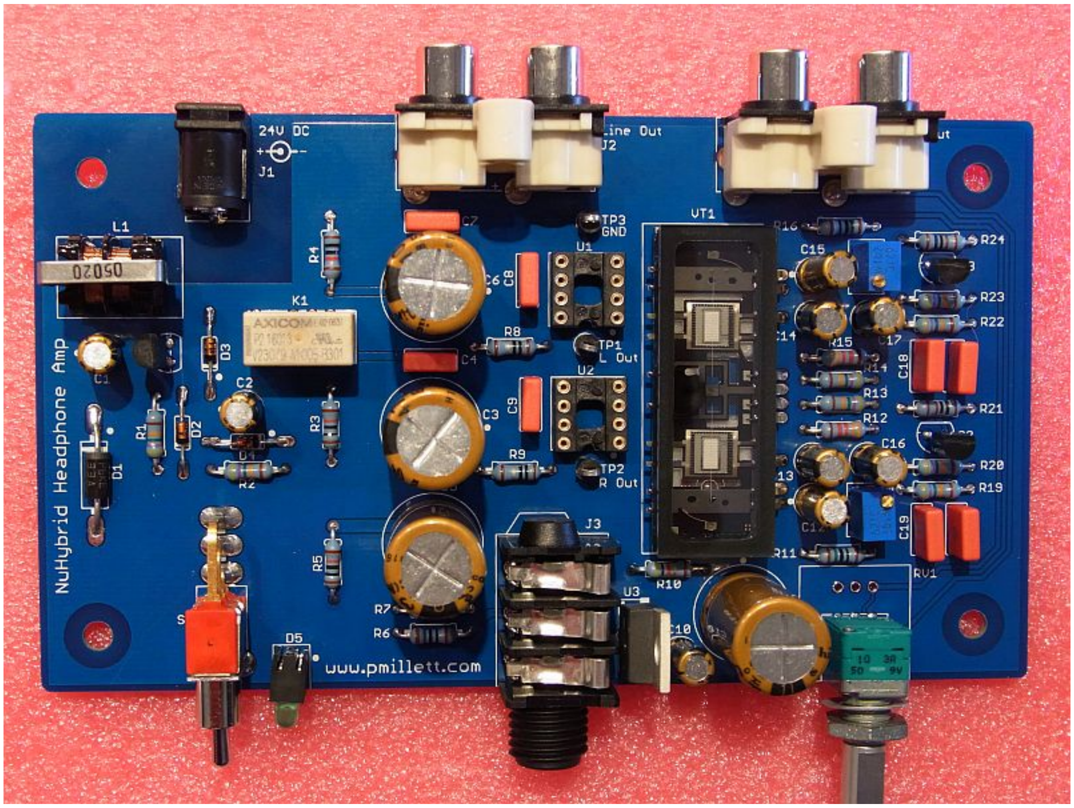


The PCB is just under 5.5" x 2.7". The size was chosen to fit into one half of a standard plastic box from Serpac.



Construction

Assembly is as simple as soldering all the parts into the PCB.



To make it easier to build, I've put together a complete detailed assembly manual. It has a lot of pictures,. so it's a pretty big (113MB) file (!) It also includes the parts list (BOM) and schematic. Since the details are all in there, I won't repeat them here on the web page.

You can also download the parts list (BOM) by itself in PDF or XLS format.

Parts come from two sources: the PCB and Nutube are sold by me through my eBay store. The rest of the parts can be bought from Mouser or DigiKey.

To make things easier, I have shared a project at Mouser that you can access and pretty much automatically buy all of the parts needed, including the plastic case, knob, and AC adapter. You can edit your cart after loading the project if you want to change anything. To access the shared project, go to http://www.mouser.com/ProjectManager/ProjectDetail.aspx?AccessID=b68a30231c or http://www.mouser.com/Tools/Tools.aspx and enter this access code: b68a30231c

Upgrades

I am often asked what can be done to upgrade the designs that I publish. In this case, there are a couple of upgrades that I will mention right out of the gate. They are also shown in the notes section of the parts list.

One is the volume control pot. Unfortunately, all small (and cheap) volume controls suck. They have lots of channel mismatch, and they are noisy or get nosier with time. The pot I used here is not bad, but it is noisy at the bottom end of travel, which bugs me. So on this PCB I put in pads for the standard (Alps or others) small cheap control, and also a TKD 2CP601. The TKD pot is available from audiophile parts sources, like Parts Connexion. It IS expensive - it costs about $40, which is a lot considering the rest of this entire amplifier will cost about $116 to build. But if you do one upgrade, I would recommend this one. Although it is possible to build it with the standard pot and install the upgrade later, it is painfully difficult to remove the small pot to replace it - if you try it, I would suggest enlist the help of a soldering expert to avoid damaging the PCB pulling it out.

You can also upgrade capacitors - the electrolytic caps I used are pretty good (Nichicon "fine gold" audio electrolytic caps and Wima polyethylene film caps), but you may want to use something else. You can also upgrade the connectors to have gold plating for a few dollars if you want.

You can substitute your favorite opamp or buffer for the OPA551. It needs to support a 24V power supply, and be unity gain stable. Other than that it's up to you.

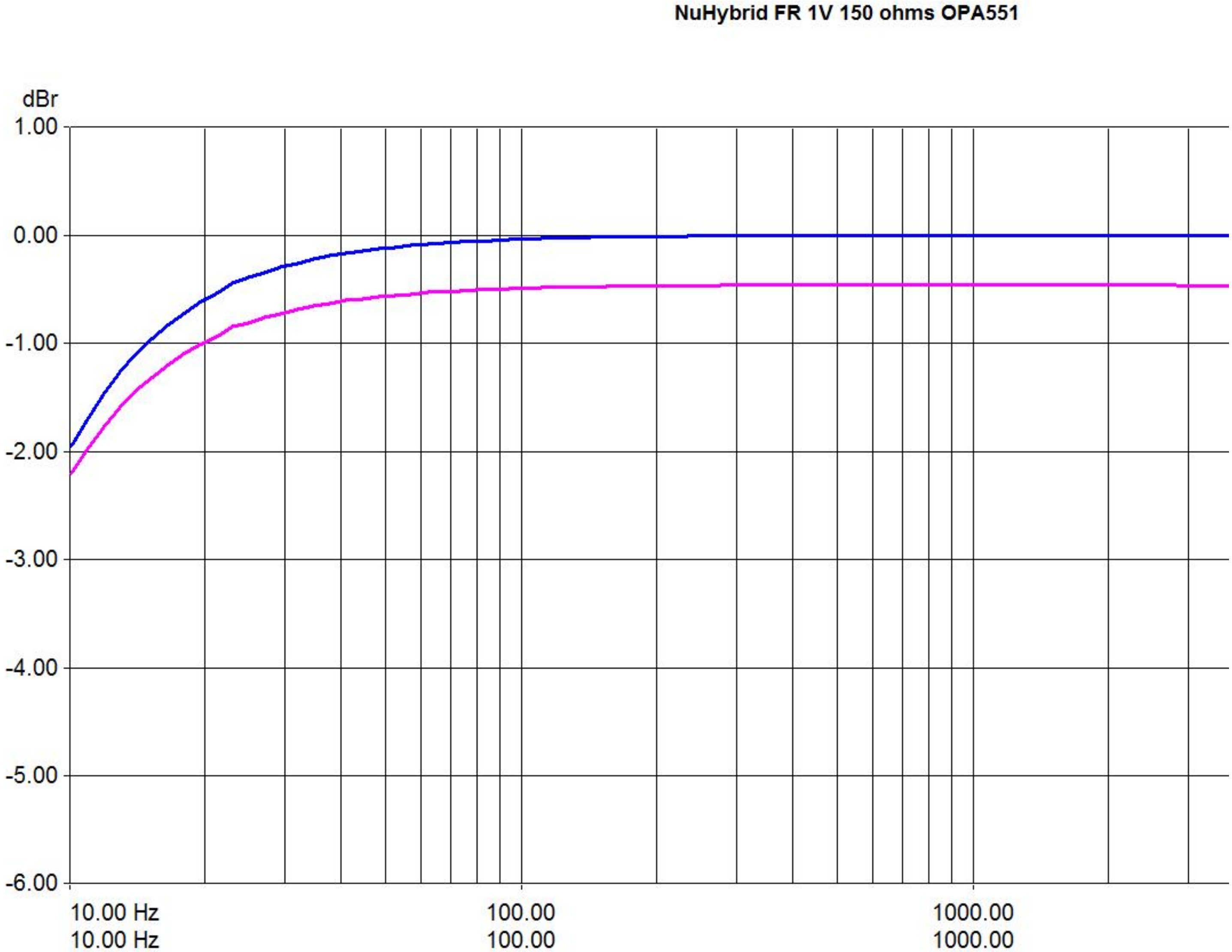
Although the 2N7002 MOSFETs make surprisingly good followers, it's possible to swap in a JFET like the 2SK170 (or LSK170). If you do that, change the load resistors from 1k to something more like 10k.

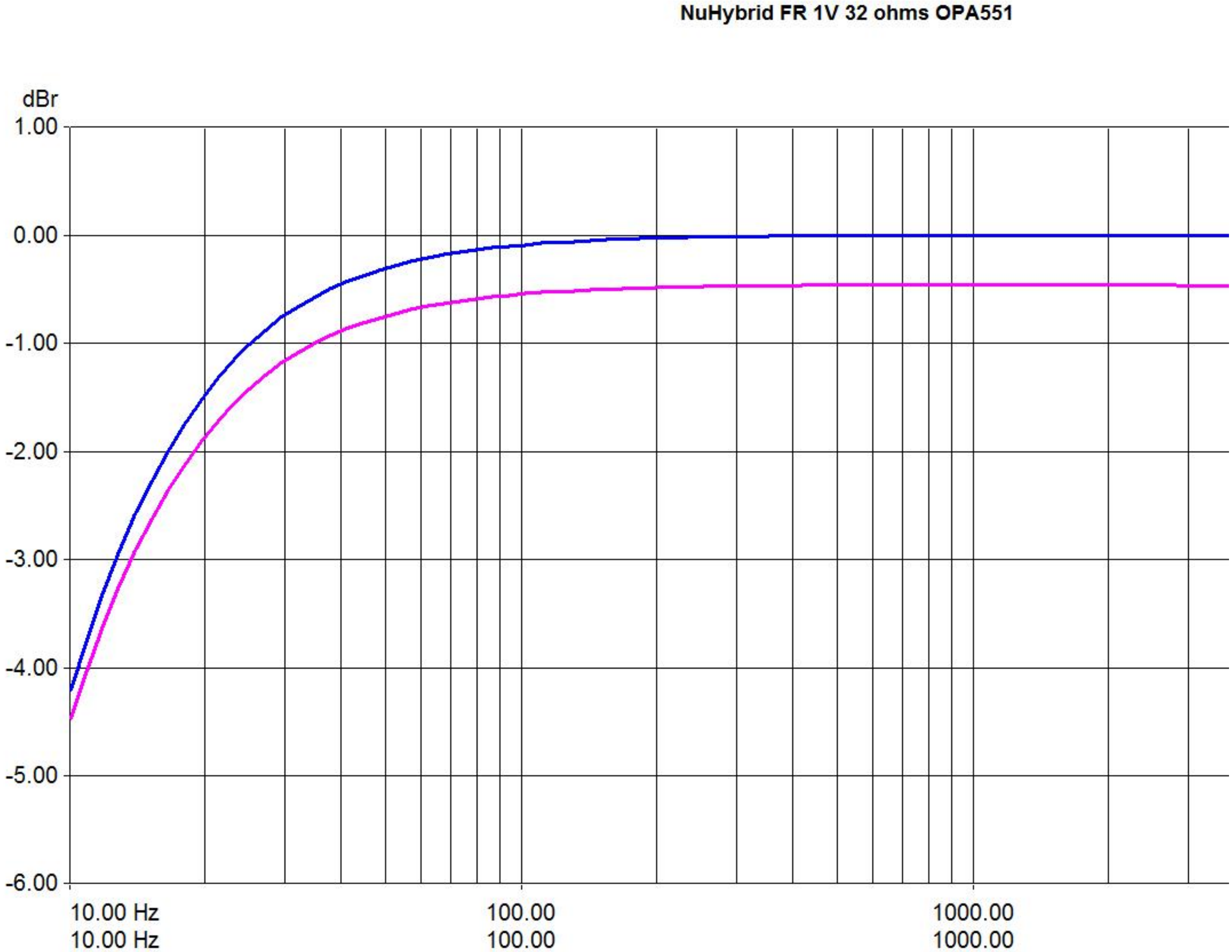
Performance & Measurements

In general, the NuHybrid amp performs a lot like the original Millett hybrid amp.

I made no attempt to tweak or trim the gain, so the gain is what you get from the Nutube stage. In this case it gives a voltage gain of about 6x. This seems OK for most applications, though its a little on the high side for IEMs and a few very high sensitivity headphones. Drive capability is limited by the output buffer. With the OPA551 used all headphones that I know of can be driven.

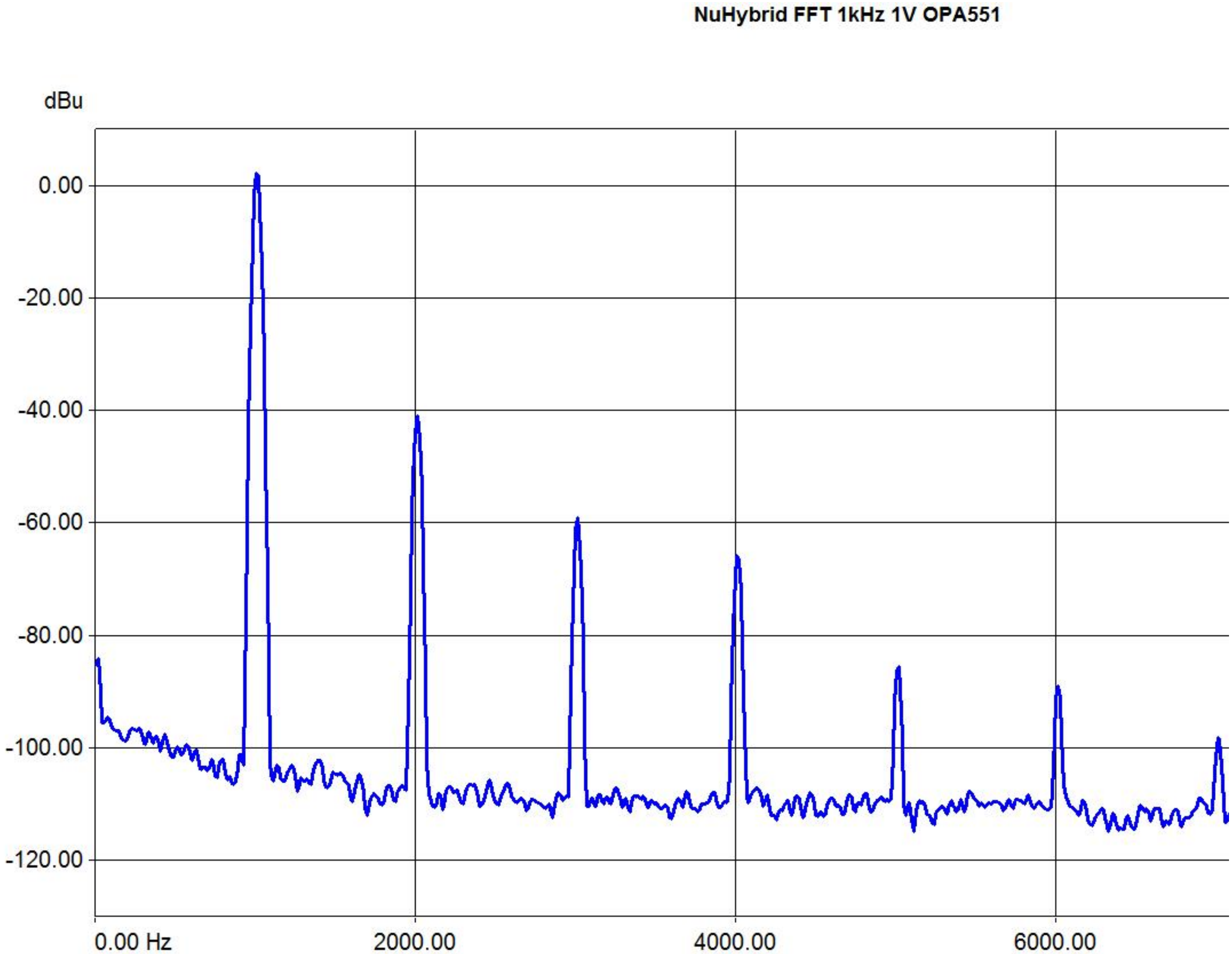
The frequency response is pretty flat. LF response is limited by the coupling caps, both at the input (in the case of high impedance headphones) and at the output (for lower impedance headphones). In any case the LF response is -3dB well below 20Hz, and the HF response drops well over 40kHz:


NuHybrid FR 1V 150 ohms OPA551
dBr
1.00
0.00
-1.00
-2.00
-3.00
-4.00
-5.00
-6.00
10.00 Hz
10.00 Hz
100.00
100.00
1000.00
1000.00



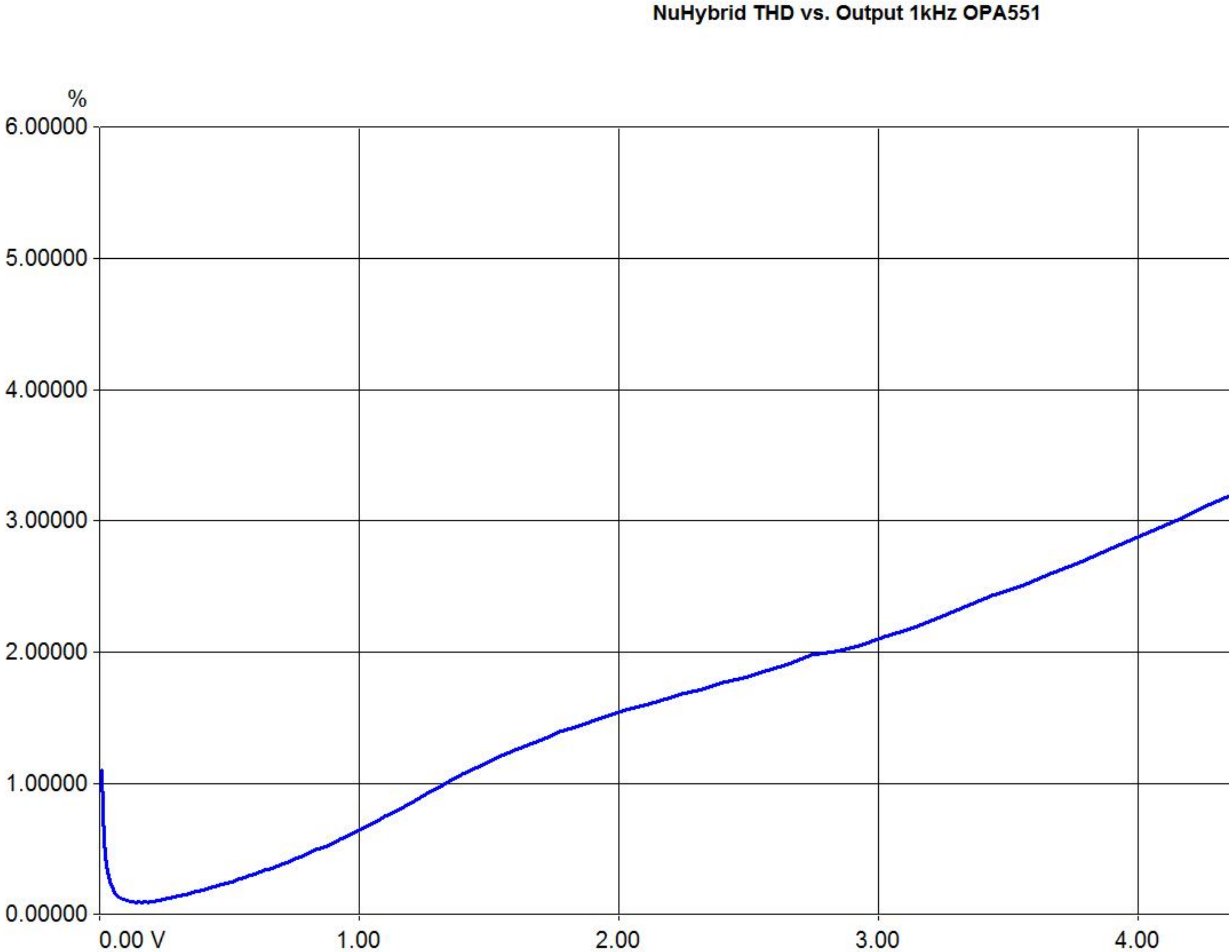
You can see a 0.5dB difference in level between L and R channels. This is due to gain mismatch between the two halves of the Nutube. I didn't provide a way to trim this, because so far the channel matching has been within 1dB, which is better than the matching of the channels in the volume control pot, and for most people inaudible.

An FFT of the output shows typical single-ended triode harmonic characteristics:



One of the cool things about this amp is that, by tweaking the bias, you can alter whet the harmonic makeup is. You can easily take the line output and feed it into a sound card input, and use a program like [Audiotester](#) to look at an FFT of the output. Then you can tweak the bias pots to tune the distortion. This FFT was taken with the bias set to give 11V at the opamp output, which is close to the minimum overall THD.

Speaking of which...



This plot shows THD+N vs. output level. At 1V RMS out (often the point we specify headphone amps), THD is about 0.6%. No, this is NOT a low distortion amplifier - it is very much like a triode amplifier with no NFB (which, in fact, it is). Clipping (5% THD) - if you can call it that, since it is more like gain compression - occurs at about 6V RMS out. Distortion shows a nice gradual rise with output voltage, with the typical noise "hook" at very low levels.

In the frequency domain, the THD is pretty flat. The rise aat high frequency is likely slew rate limiting. But look at the scale - even at 20kHz, the THD only rises form 0.63% to 0.73%.

The Sound

I always hate to try and answer the question, "Yeah, I see the measurements, but what does it *sound* like?"

The engineer in me will simply say that it sounds like the measurements look!

OK... it sounds like what it is - a single-ended triode amplifier. The characteristics of the Nutube dominate the sound of the amplifier. The solid state parts have such low distortion that they really do not contribute much. Along the same lines, I would say that it sounds a lot like the original "Millett Hybrid" - perhaps slightly more "tubey", especially at high volumes. Using the OPA551 removes a little of the high-order distortion products that were caused by the BUF634 in the original hybrid.

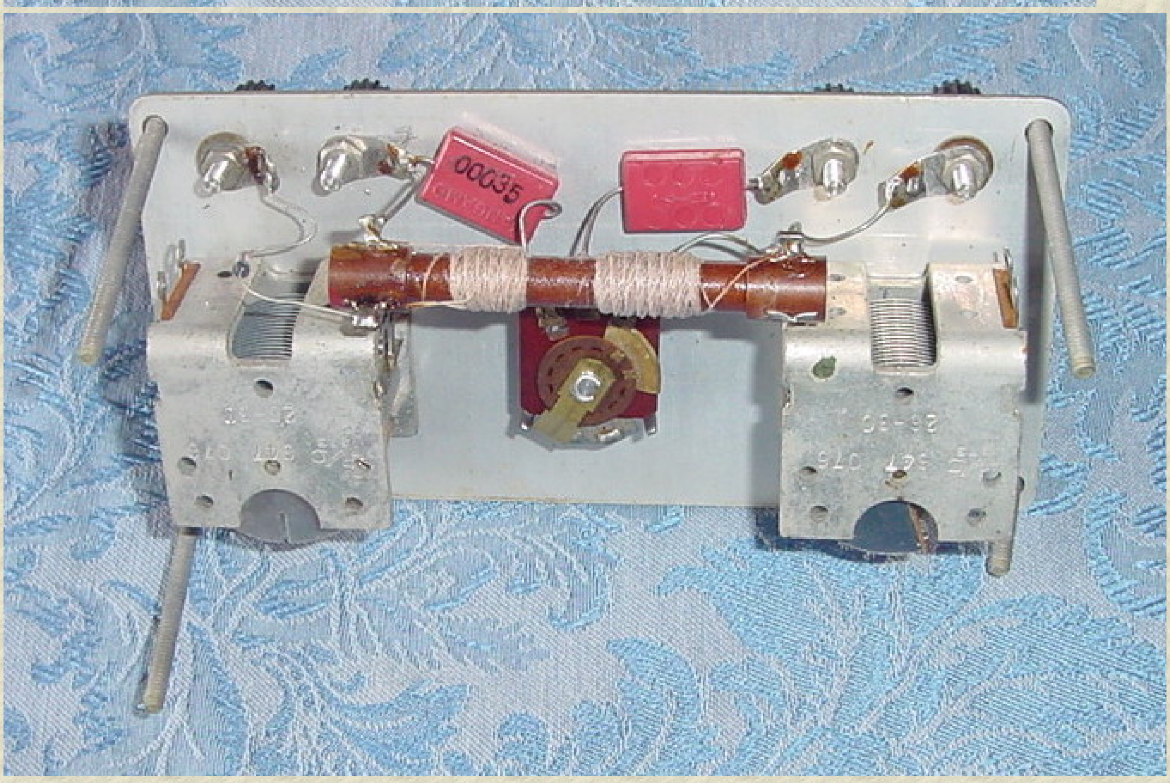
Or... I think it sounds pretty good! I've been sitting here listening to it the entire time I've been writing this web page, through some Sennheiser HD600's. Very pleasing.

Homebrew Crystal Radios for Sale

Back to Scott's Crystal Radios

Email to scottswim@aol.com

Heathkit CR1 Crystal Radio #3




CRYSTAL RECEIVER
MODEL CR-1
PHONES
DET.

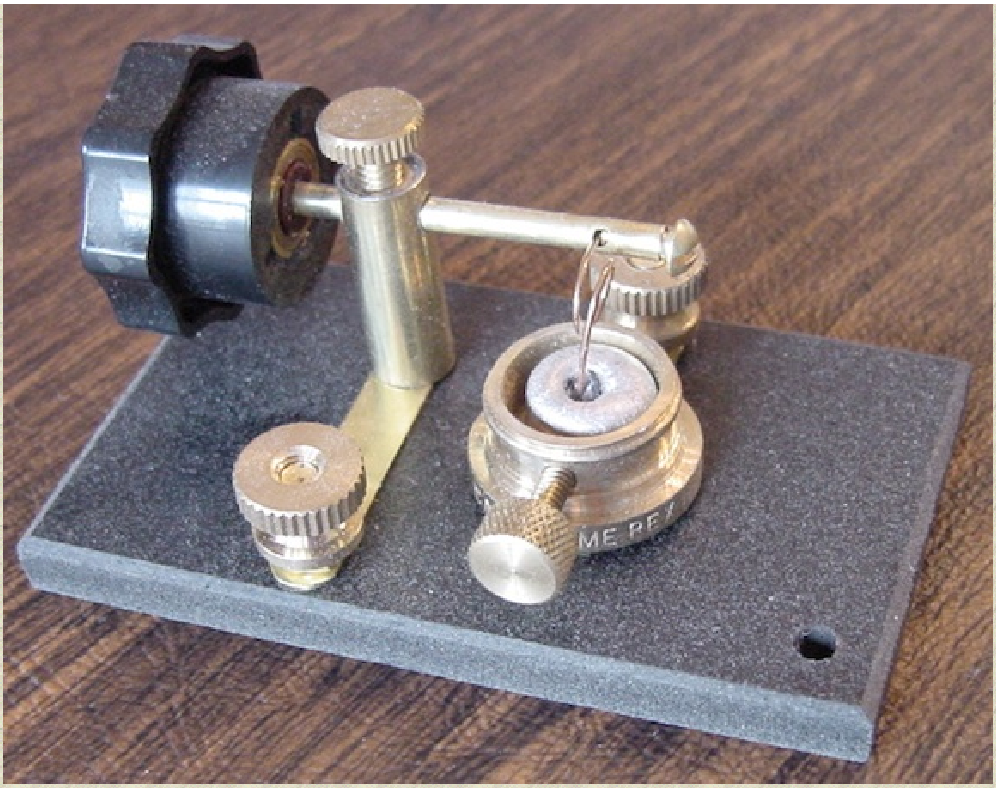

Heathkit
CRYSTAL RECEIVER
MODEL CR-1
ANT.
GND.
ANT.

This Heathkit CR-1 Crystal Radio has one unfortunate chip in a corner someone tried to repair, and a scratch on the faceplate, neither of which affect the function of the radio. Also there is a little patch of tape residue on the top surface. It works fine, and the internal parts appear untouched. $89SOLD

Miller Model 595 High Fidelity AM tuner crystal radio

The Miller 595 High Fidelity Tuner is actually a dual tuned circuit crystal radio praised as the most selective crystal radio ever made. This is made possible by the dual tuned bandpass circuit and the vernier gear reduction tuning drive mechanism. This set is in good working condition, and the cosmetic condition is good or better with some minor scratches on top and fading on the faceplate. Tested and working and I can pick up 10 or so stations here with a 15 foot indoor wire antenna. The original output cord can plug into an amplifier or you can hook up high impedance headphones. $125

Crystal Radio Detector Stand
NEW REPRODUCTION OF A 1930S CRYSTAL RADIO DETECTOR STAND
MADE AS ORIGINAL WITH SOLID BRASS AND OLD STYLE 2 X 3 PHENOLIC BASE.
COMPLETE WITH BRASS TESTED CATWHISKER BUT LESS CRYSTAL.
PRICE IS $39.00 WITH PREPAID SHIPPING TO THE US.



CONTACT dick korf
threepalms13@gmail.com

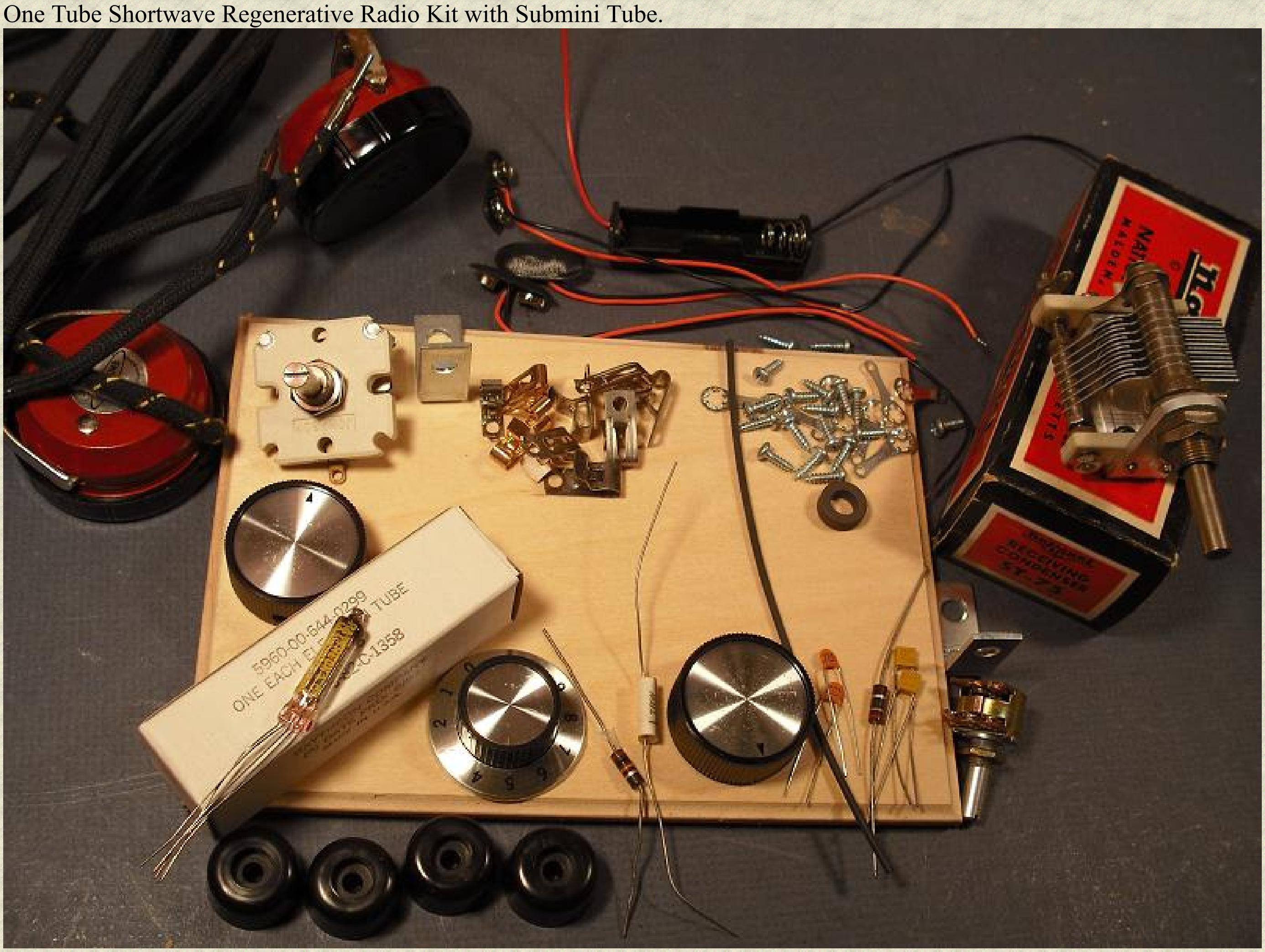
Reproduction Crystal Detector with catwhisker and mineral selection

Click photo for a larger view.
Nice reproduction of 1920's style detector on a 2"x2" solid oak base. Features a large 5/8" diameter brass ball-and-sleeve assembly in a tight, spring brass bracket that never comes loose, or needs realigning. Precision ball-and-sleeve provides silky smooth movement with no pull or backlash. Includes a selection of loose minerals., catwhisker wire, printed instructions, and a history of the mineral detector. $24.95 plus shipping. These are available directly from the manufacturer, Larry Pizella, but I don't have anymore is stock, so just click HERE to see the order page for detectors directly from the maker.

Simple Loose Coupled Crystal Radio with Headphones #4

This is a simple little crystal set made on a nicely finished breadboard type plaque, has a 2 circuit loose coupled circuit, with a diode, variable capacitor with dial knob, and Fahnstock clips for the antenna, ground and headphone connections. Complete with Cannon Alnico 1000 ohm high impedance single sided headphones. Just hook up antenna and ground and it picks up loads of AM stations here. $39

One Tube Shortwave Regenerative Radio Kit with Submini Tube.



This is a kit of parts to make a one tube regenerative shortwave radio based on a 6418 subminiature tube. It includes all the parts

needed to make the radio as shown above, with vintage National porcelain tuning condenser new old stock in original box, Johnson trimmer capacitor, ferrite toroid coil core, breadboard, and all necessary electronic components, hardware, wire, and a pair of Newcomb high impedance headphones. There is a set of detailed instructions, plus schematic and diagrammatic sketches to aid construction. I have enough parts for 4 sets right now, may be some variation in the knobs available. $49SOLD OUT plus shipping. Inquire if interested and I should be able to put together the parts for another kit but am out of the variable capacitors now

Available Upgrades: upgrade to better used vintage headphones

Upgrade to Trimm Dependable 2000 ohm headphones.... add $10

Upgrade to vintage Brandes Superior Matched Tone 2000 ohm headphones... add $20

Below is a photo of a completed set, using slightly different parts. The frequency range as tested was 5.5-9 MHz, but the coil can be modified to other frequencies.

Will be making more in the next few weeks.

Email to scottswim@aol.com

Headphone Heaven (Headphones for Sale)

BOOKS for Sale

Back to Scott's Crystal Radios

Shipping:

Insurance is highly recommended as I can not provide refund for any item that is damaged or disappears in the mail, unless I can collect the insurance.

Click on icon to calculate shipping charges via US Mail from my zipcode of 23320

UNITED STATES POSTAL SERVICE

Search Stamps Change of Addr. ZIP Codes
Rate Calculator Express Mail Tracking Home

RF Power Amplifier Design

Markus Mayer & Holger Arthaber
Department of Electrical Measurements and Circuit Design
Vienna University of Technology

June 11, 2001

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Contents

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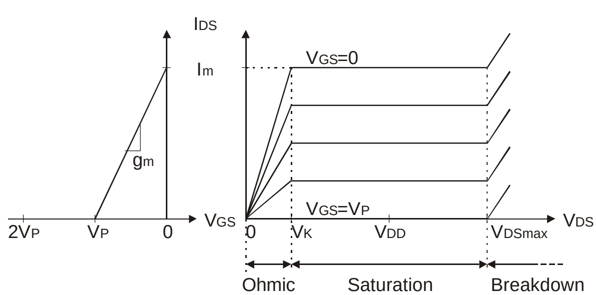
Efficiency Definitions

- Drain Efficiency: $h_D = \frac{P_{OUT}}{P_{DC}}$

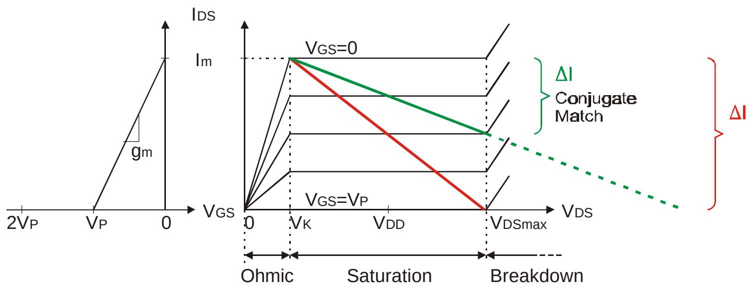
- Power Added Efficiency: $h_{PA} = \frac{P_{OUT} - P_{IN}}{P_{DC}} = h_D \cdot \left(1 - \frac{1}{G}\right)$

Ideal FET Input and Output Characteristics



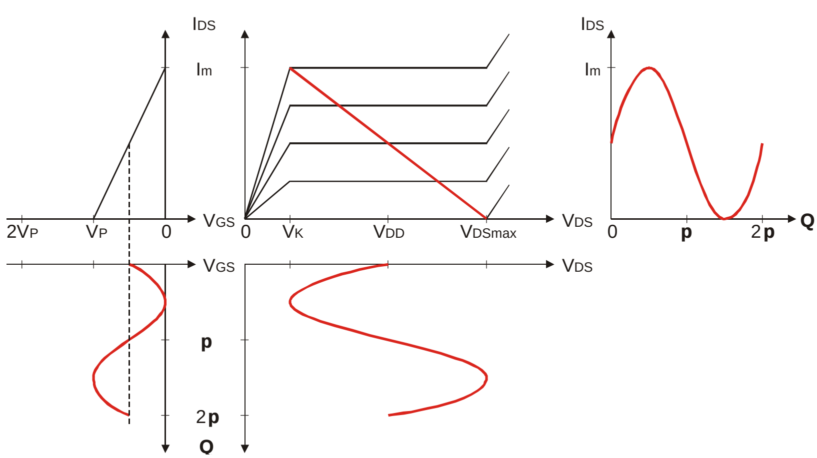
$$k = \frac{V_{DD} - V_K}{V_{DD}}$$

Maximum Output Power Match

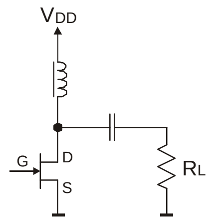


$$R_{OPT} = \frac{V_{DS\max} - V_K}{I_m}$$

Class A



Class A – Circuit

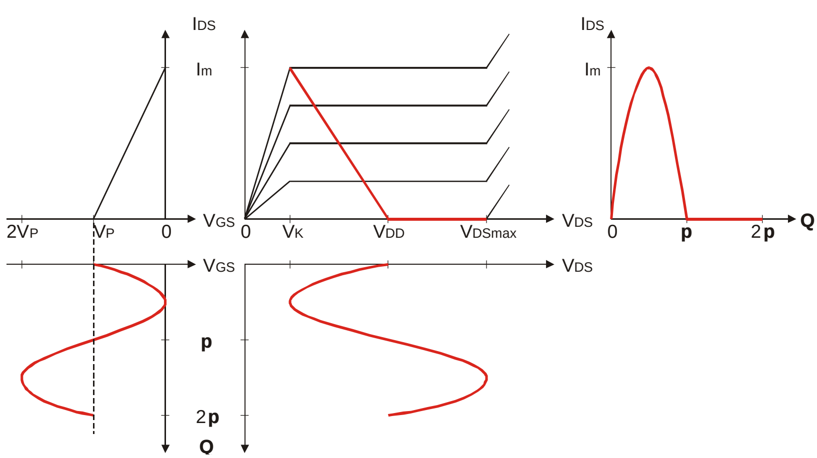


$$h_D = k \cdot 50\%$$

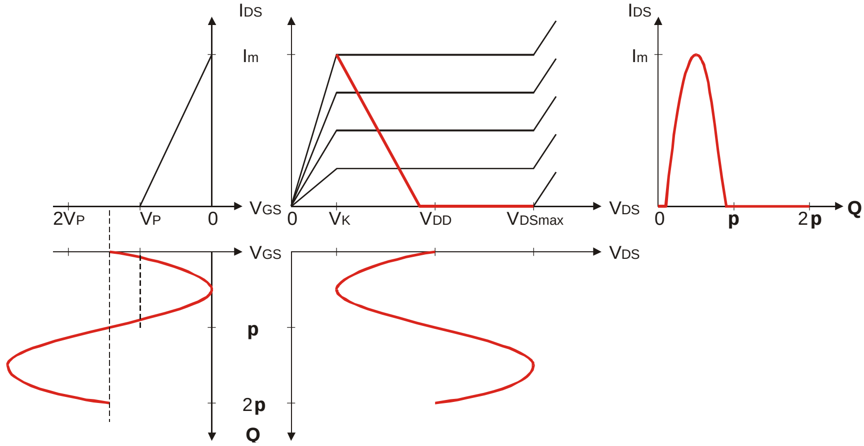
$$G = G_A \quad (\text{e.g.}\,14\,\text{dB})$$

$$h_{PA} = k \cdot 48\%$$

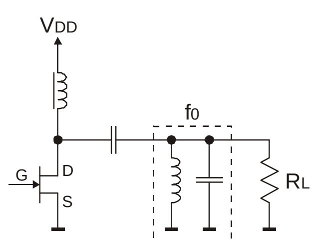
Class B



Class C

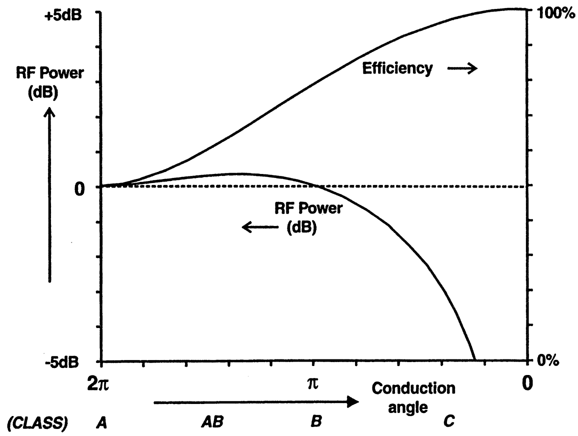


Class B and C – Circuit

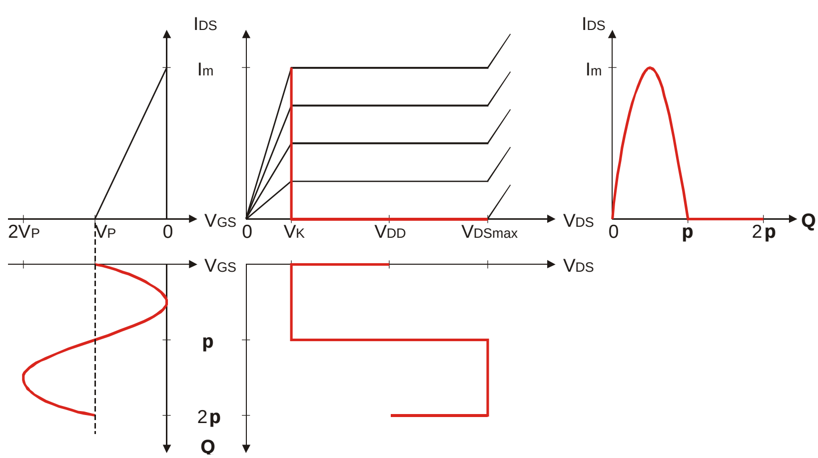


<u>Class B</u>	<u>Class C</u>
$h_D = k \cdot 78\%$	$h_D \rightarrow 100\%$
$G = G_A$ - 6dB (8 dB)	$G \rightarrow 1$
$h_{PA} = k \cdot 65\%$	$h_{PA} \rightarrow 0\%$

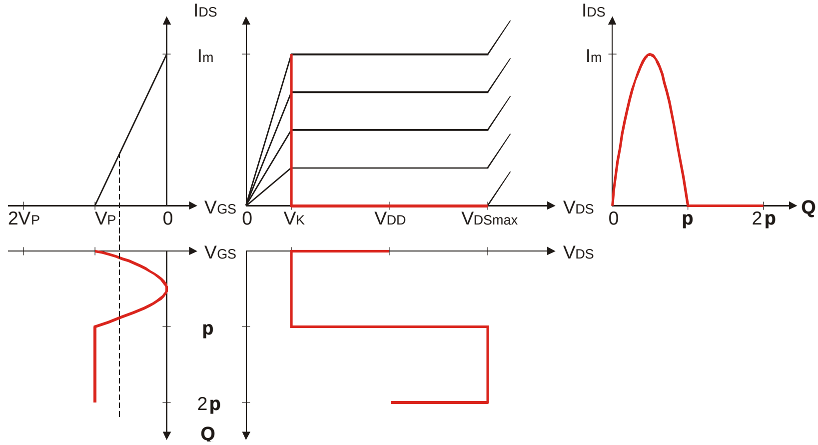
Influence of Conduction Angle



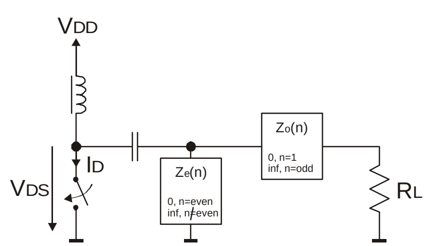
Class F (HCA ... harmonic controlled amplifier)



hHCA (half sinusoidally driven HCA)

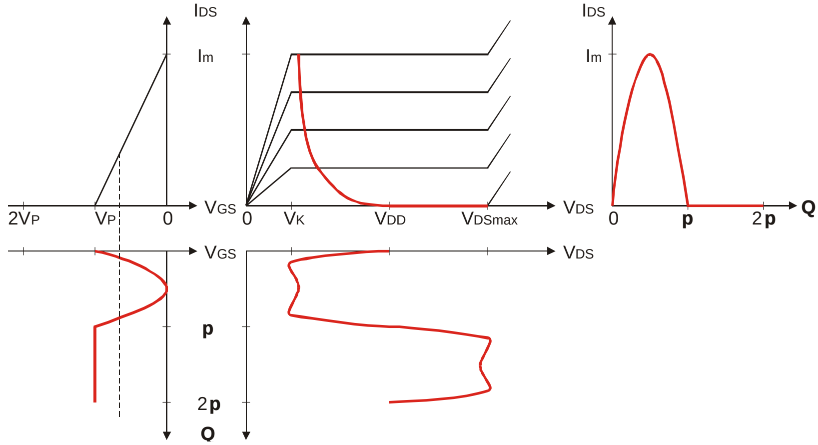


Class F and hHCA – Circuit

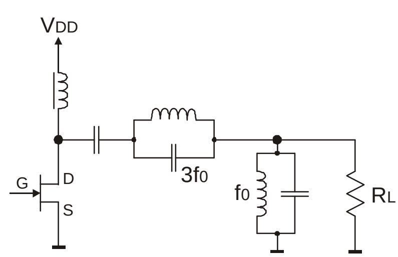


Class F	hHCA
$h_D = k \cdot 100\%$	$h_D = k \cdot 100\%$
$G = G_A - 5\text{dB}$ (9 dB)	$G = G_A + 1\text{dB}$ (15 dB)
$h_{PA} = k \cdot 87\%$	$h_{PA} = k \cdot 96\%$

hHCA – Third Harmonic Peaking



Third Harmonic Peaking – Circuit

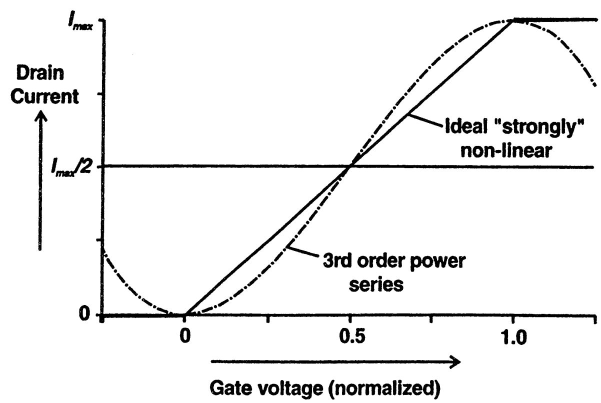


$$h_D = k \cdot 91\%$$

$$G = G_A + 0.6\text{dB} \quad (14.6\,\text{dB})$$

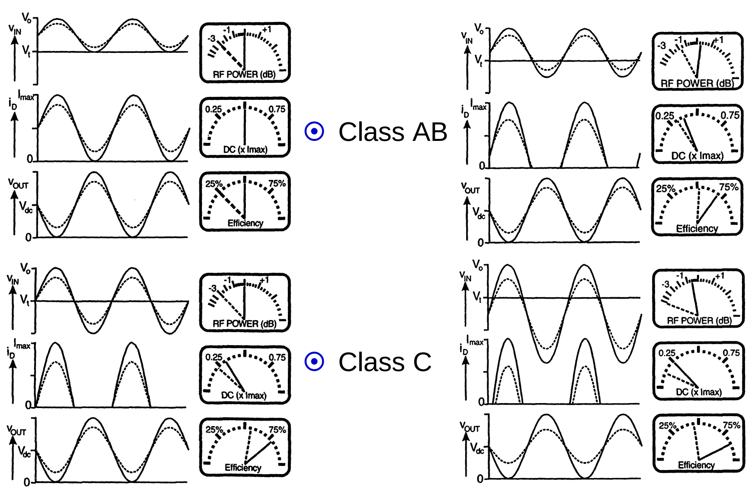
$$h_{PA} = k \cdot 87\%$$

Linearity Aspects

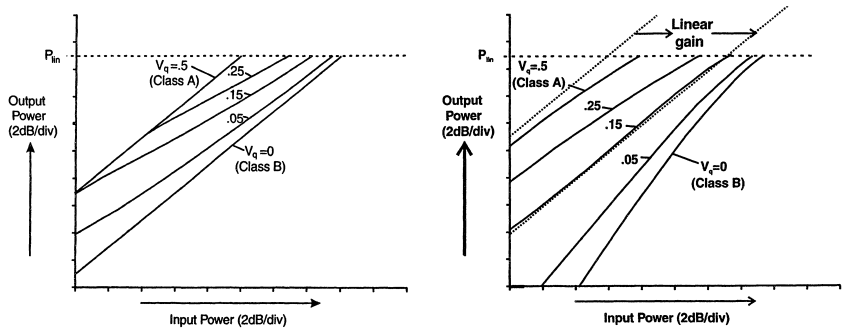


Linearity Aspects

- Class A
- Class AB
- Class B
- Class C



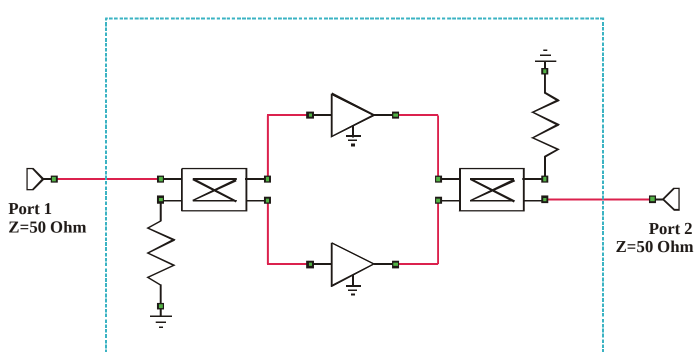
Linearity Aspects



- Ideal strongly nonlinear model
- Strong-weak nonlinear model

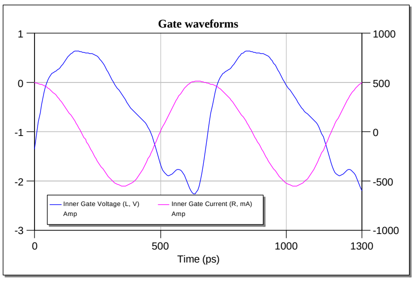
Amplifier Design – An Example

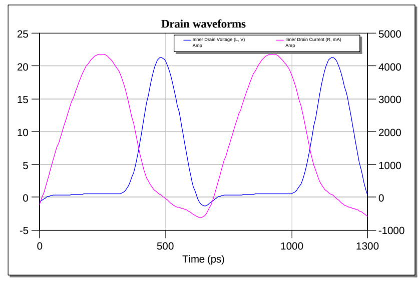
- Balanced Amplifier Configuration



Amplifier Design – Simulation

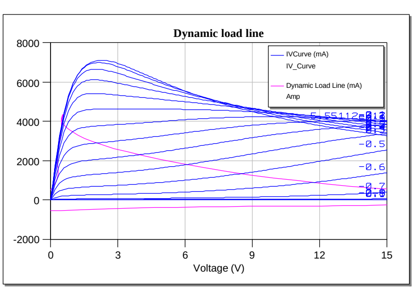
- Gate & Drain Waveforms

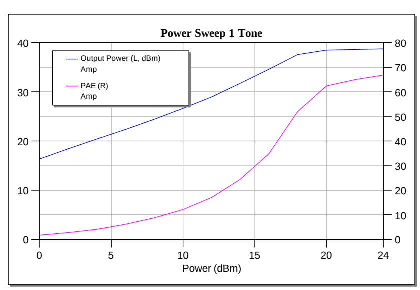




Amplifier Design – Simulation

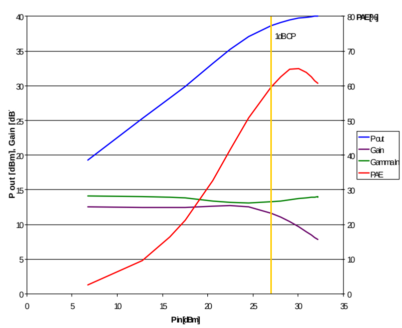
- Dynamic Load Line & Power Sweep

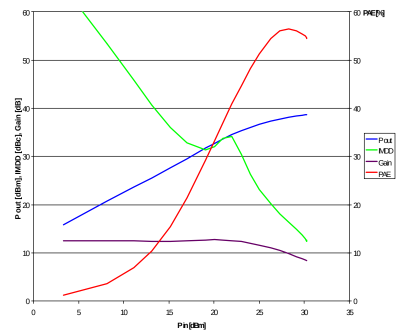




Amplifier Design – Measurements

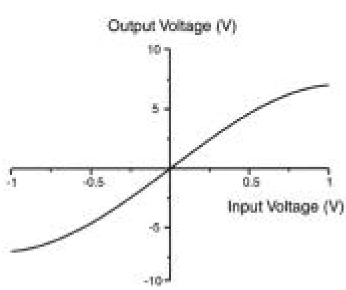
- Single Tone & Two Tone

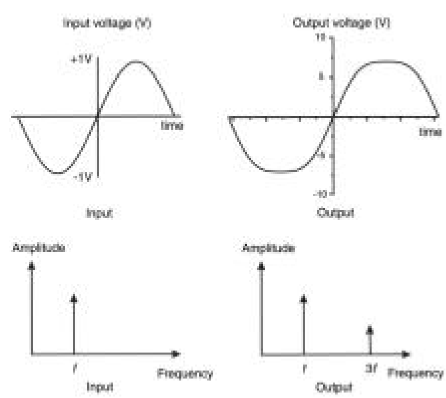




Amplifier Nonlinearity

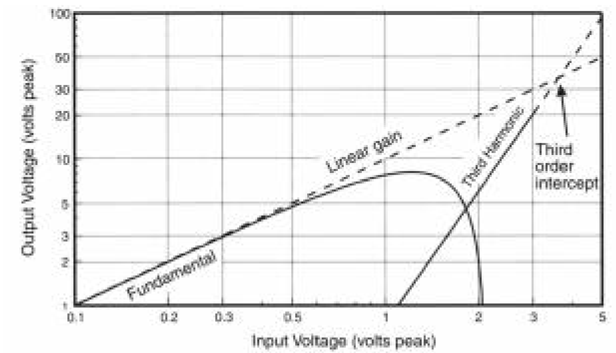
- Gain and Phase depends on Input Signal
- 3rd Order Gain-Nonlinearities:





Amplifier Nonlinearity

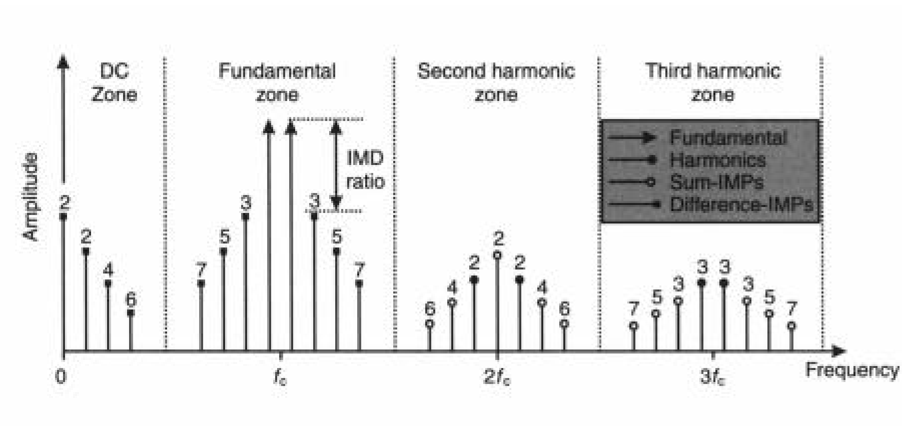
- Higher Output Level (close to Saturation) results in more Distortion/Nonlinearity



Nonlinearity leads to?

- Generation of Harmonics
- Intermodulation Distortion / Spectral Regrowth
- SNR (NPR) Degradation
- Constellation Deformation

Intermodulation and Harmonics



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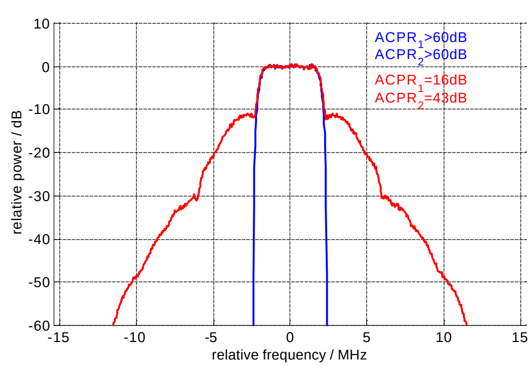
Spectral Regrowth



- Energy in adjacent Channels
- ACPR (Adjacent Channel Leakage Power Ratio) increases

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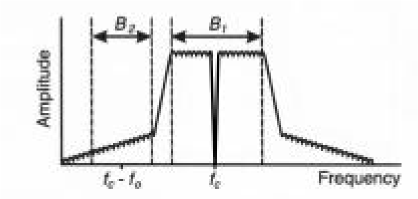
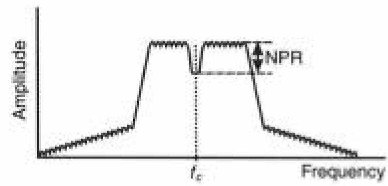
Reduced NPR (Noise Power Ratio)

- Input Signal



- Output Signal of Nonlinear Amplifier



- Degradation of Inband SNR
- „Noisy“ Constellation

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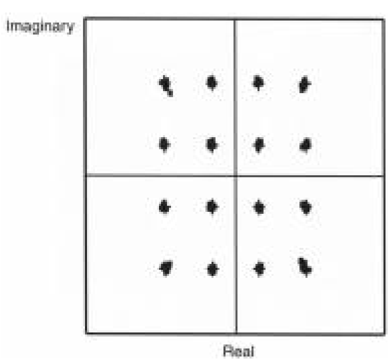
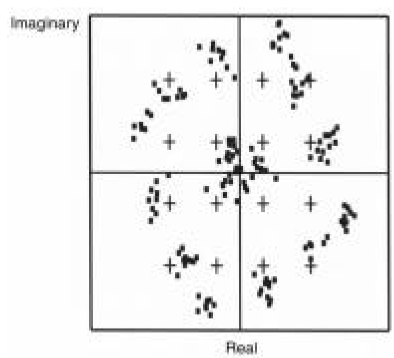
Constellation Deformation

- Input Signal



- Output Signal of Nonlinear Amplifier (with Gain- and Phase-Distortion)



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Modeling of Nonlinearities

- with Memory-Effects
  - Volterra Series (=„Taylor Series with Memory“)

- without Memory-Effects
  - Saleh Model $f(r)=\frac{a_a r}{1+b_a r^2}$ $g(r)=\frac{a_\Theta r^2}{1+b_\Theta r^2}$
  - Taylor Series
  - Blum and Jeruchim Model
  - AM/AM- and AM/PM-conversion

better performance

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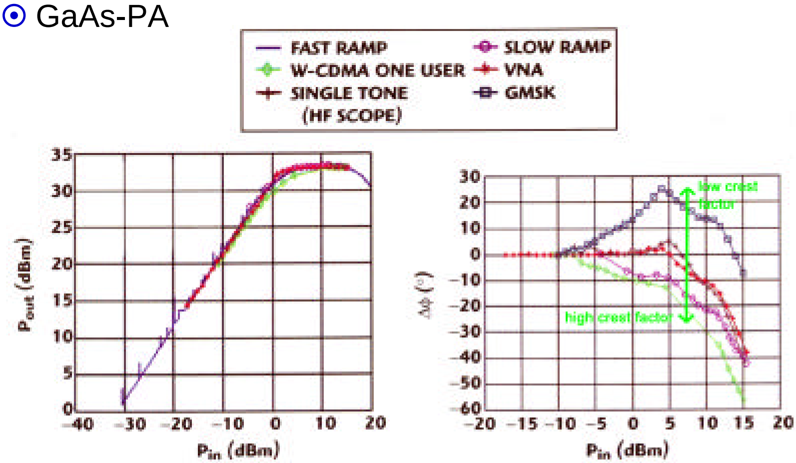
AM/AM- and AM/PM-Conversion

- GaAs-PA



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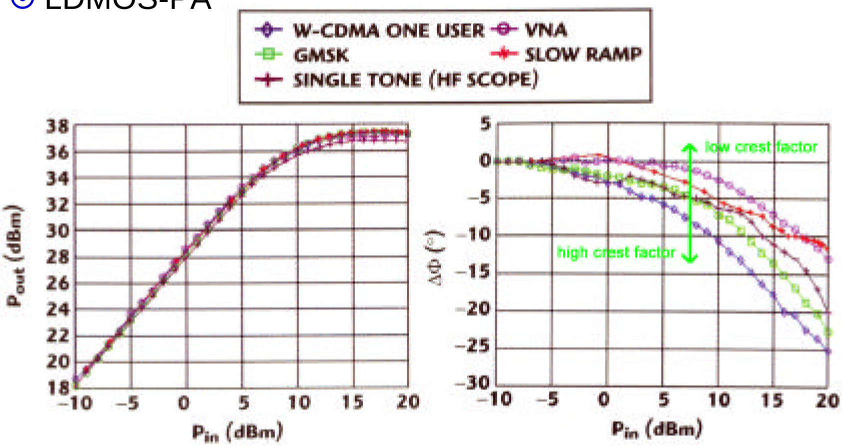
AM/AM- and AM/PM-Conversion

- LDMOS-PA



How to preserve Linearity?

- Backed-Off Operation of PA
  - Simplest Way to achieve Linearity
- Linearity improving Concepts
  - Predistortion
  - Feedforward
  - ...

How to preserve Efficiency?

- Efficiency improving Concepts
  - Doherty
  - Envelope Elimination and Restoration
  - ...
- Linearity improving Concepts
  - Higher Linearity at constant Efficiency
    → Higher Efficiency at constant Linearity

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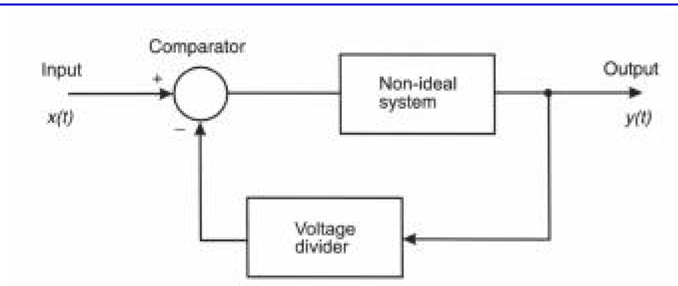
Direct (RF) Feedback



- Classical Method
- Decrease of Gain → Low Efficiency
- Feedback needs more Bandwidth than Signal
- Stability Problems at high Bandwidths

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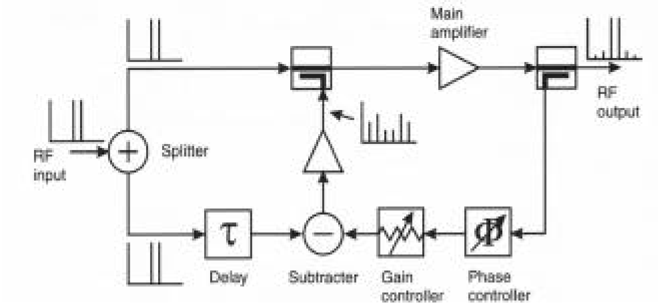
Distortion Feedback



- Feedback of outband Products only
- Higher Gain than RF feedback
- Stability Problems due to Reverse Loop

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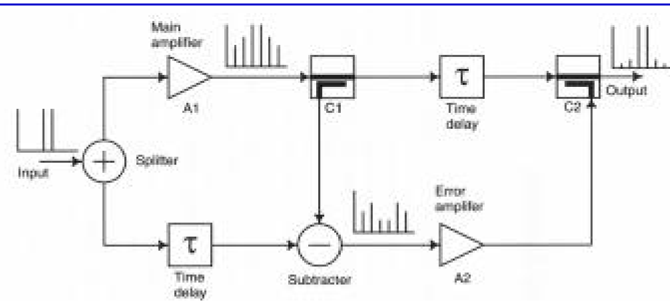
Feedforward



- Overcomes Stability Problem by forward-only Loops
- Critical to Gain/Phase-Imbalances
  0.5dB Gain Error → -31dB Cancellation
  2.5° Phase Error → -27dB Cancellation
- Well suited for narrowband application

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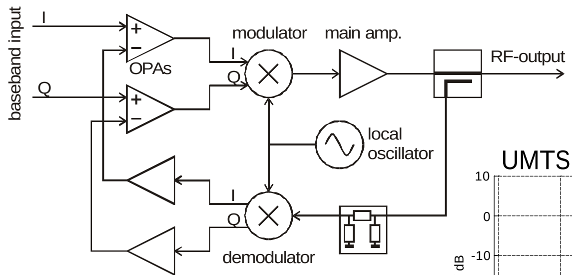
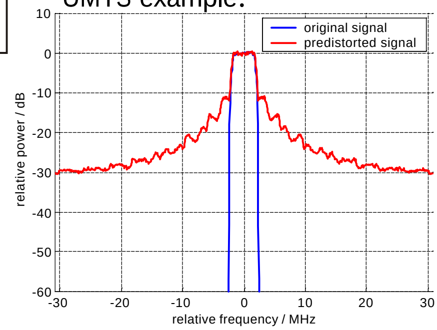
Cartesian Feedback



UMTS example:



- AM/AM- and AM/PM-correction
- High Feedback-Bandwidth
- Stability Problems

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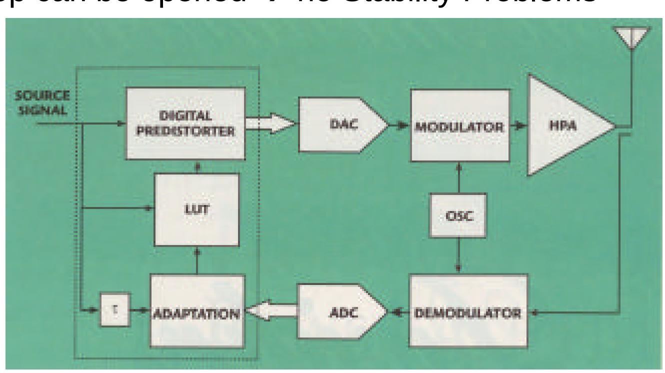
Digital Predistortion

- Digital Implementation of „Cartesian Feedback“
- Additional ADCs, DSP Power, Oversampling needed
- Loop can be opened → no Stability Problems



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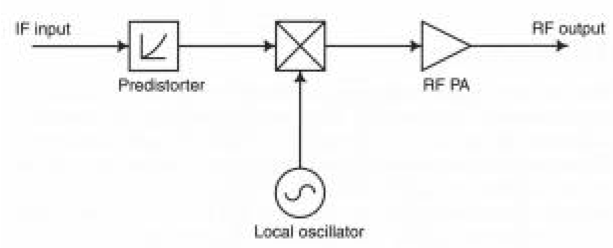
Analog Predistortion



- Predistorter has inverse Function of Amplifier
- Leads to infinite Bandwidth (!)
- Hard to realize (accuracy)

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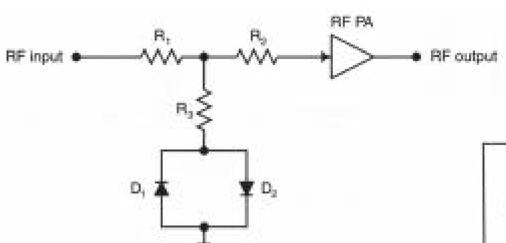
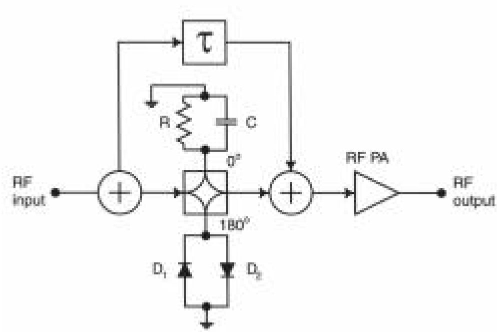
Analog Predistortion

- Possible Realizations:





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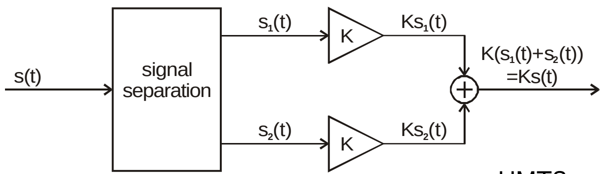
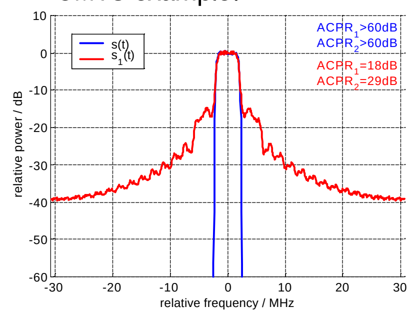
LINC (Linear Amplification by Nonlinear Components)



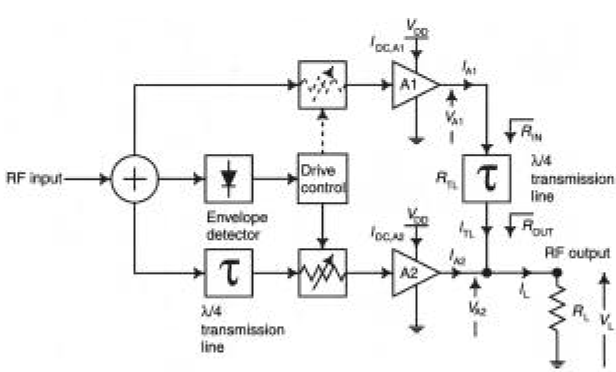
- AM/AM- and AM/PM-correction
- Digital separation required (accuracy!)
- High Bandwidth, oversampling necessary
- Stability guaranteed

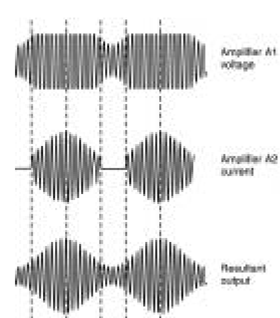
UMTS example:



Doherty Amplifier

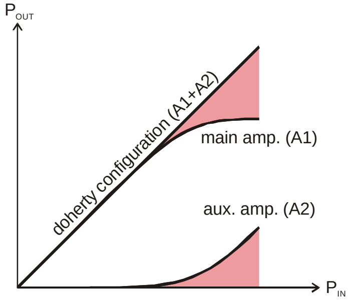
- Auxiliary amplifier supports main amplifier during saturation
- PAE can be kept high over a 6dB range



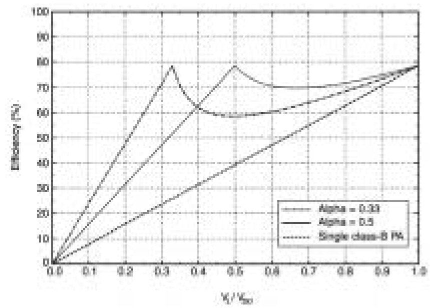


Doherty Amplifier

- Gain vs. Input Power



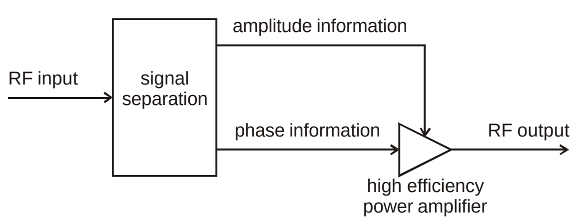
- Efficiency vs. Input Power



- No improvement of AM/AM- and AM/PM-distortion
- Behavior of auxiliary amplifier very hard (impossible) to realize
- Stability guaranteed

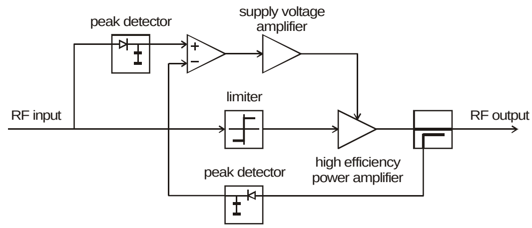
EER (Envelope Elimination and Restoration)

- Separating phase and magnitude information
- Elimination of AM/AM-distortion
- Application of high-efficient amplifiers (independent of amplitude distortion)
- Stability guaranteed

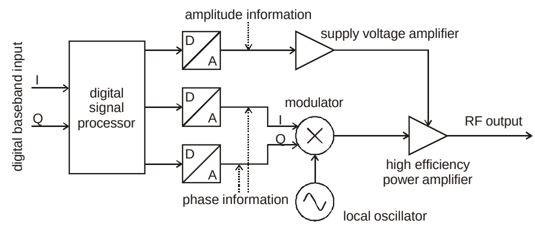


EER (Envelope Elimination and Restoration)

- Analog realization
  - Limiter hard to build
  - Accuracy problems
  - Feedback necessary



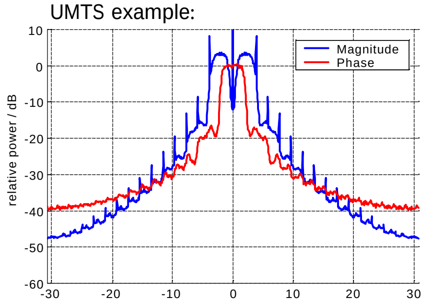
- Digital realization
  - Oversampling + high D/A-conversion rates required
  - High power consumption of DSP and D/A-converters
  - Possible feedback elimination
  - Compensation of AM/PM-distortion possible



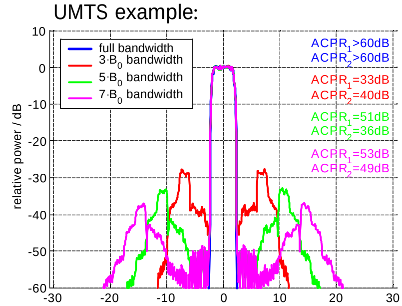
EER (Envelope Elimination and Restoration)

- Bandwidth of Magnitude- and phase-signal have higher than transmit signal
- Five times (!) oversampling necessary to achieve standard requirements

UMTS example:

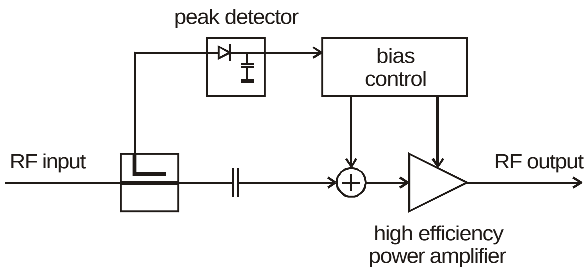


UMTS example:



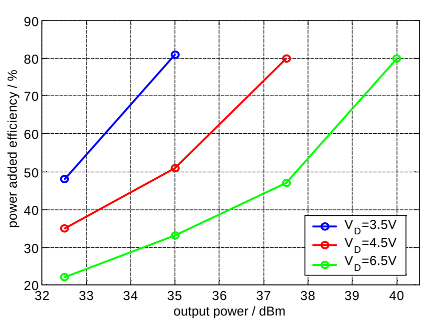
Adaptive Bias

- Varying/Switching of Bias-Voltage depending on Input Power Level
- Selection of Operating Point with high PAE
- Applicably for nearly each type of Amplifier



Adaptive Bias

- Single tone PAE for switched V_{DD} with V_G kept constant



- Simply to implement Concept
- Stability guaranteed
- Possible problems:
  - DC-DC converter with high efficiency necessary
  - Possible Linearity Change (can increase and decrease) especially for HCAs

Summary

- Digital Realization required to achieve Accuracy
- Problem of Stability for high Bandwidth Application
- Higher Bandwidths (Oversampling) necessary, depending on Order of IMD cancellation
- Predistortion gives best Results while keeping Efficiency high (valid for high Output Levels > 40dBm)

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Figure References

- F. Zavosh et al,
  “Digital Predistortion Techniques for RF Power Amplifiers with CDMA Applications”,
  Microwave Journal, Oct. 1999
- Peter B. Kenington,
  “High-Linearity RF Amplifier Design”,
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- Steve C. Cripps,
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  Artech House, 1999

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Homebrewing for QRP SSB

First I would like to mention my website www.jessystems.com or in case you forget the site URL, just google my call sign N6QW. Many of my projects are documented there, complete with schematics and links to hints and tips that maybe helpful if you are contemplating building a homebrew QRP SSB transceiver. As an aside I have formally documented much of what we will discuss in this podcast and that document will be up on my website so you can download the circuits and details.

Homebrewing a QRP SSB transceiver is a very interesting subject and one that often “scares” homebrewers who would like to move from the less complex CW transceiver to ones where a rag chew is something other than a blur of sounds at 35 WPM.

But the changes necessary to transition to a homebrew QRP SSB transceiver are not that great and can be readily accomplished if the design is thought of in terms of a process. You will hear me talk a lot about process and processes.

The very 1st step in any homebrew process is to be prepared for the project and that perhaps is the very thing that determines whether your project is successful or “sorta kinda worked –once”. There is no rocket science to the preparation phase just some logical thinking and below is my list of things that need to be in place:

- Reference library, much of which can be found on the internet. But that also includes setting up your filing system on your computer so that the data can be readily accessed. I have folders on my computer that include spec sheets for my favorite devices, articles and documentation from others as well as information on my projects

- Basic test equipment including a wide range crystal test oscillator, RF probe, DVM, 0-1 amp DC meter, signal source like a DDS. An Oscilloscope is really handy and almost a necessity. An LC meter such as available from AADE is another handy item that once you have you wonder why you waited so long to get one.

- Basic tools such as a temperature controlled grounded soldering iron with interchangeable fine tips, good quality needle nose pliers, various screwdrivers, exacto knife, tweezers and LED flashlight.
- Junque Box. Purchase parts in bulk and save big time. I purchase 2N3904 and 2N3906 resistors typically for 3 cents a piece buying 100 at a time. Many parts seem to show up over and over again like 100NF and 10NF capacitors, 1N4148 diodes, LM386 audio amps, NE5534's op amps, 2N2219 (good cheap RF transistor), ferrite cores such as the FT 37-43, iron cores such as T-37-6, T50-6, T68-6, T68-2, etc. See http://www.jessystems.com/How%20To%20Stuff%20A%20Junk%20Box where most of these common parts have been identified.

As a prelude to Homebrewing a QRP SSB transceiver, one of the most critical elements is the choice of IF (Intermediate Frequency) since most of the less complex designs are single conversion. This is where some time spent with a calculator can pay off big dividends. Typically (for very good technical reasons) both commercial and homebrew filters are in the range of 3 to 12 MHz. Thus to operate on the ham bands means that the LO (local oscillator) when mixed with the incoming signal results in the IF frequency. 9.0 MHz has been a popular IF frequency and when you mix that with a 5.0 MHz LO results in either 80 Meters (3.8 + 5.2 = 9) or 20 Meters (14.2 – 5.2 = 9). So one can get two bands with one filter and one LO –the band switching of course has to include the proper band pass filters so that only the band selected is received. But that choice of 9.0 MHz is not ideal for 17 Meters as the LO would have to be on about the same frequency as the IF. This presents all sorts of mixing problems. [Mixing problems arise where harmonics of oscillators or frequency generating circuits fall within amateur (or commercial bands) other than the one intended. This will make the FCC very unhappy.]

In looking at the design of the Elecraft K2, I noticed the designer's picked 4.9152 MHz for the IF frequency. Well that lit a big bulb for me. With that IF, which happens to be a standard computer crystal frequency that can be had for less than 50 cents each, there are many more possibilities for the ham bands. If you took several 11.52 MHz computer crystals and built a Super VXO which means you can actually vary that crystal frequency over

a fairly wide range and then pass that signal through a diode doubler circuit where the resulting signal is 23.04 MHz –rock solid stable. Now 23.04 – 4.9152 = 18.125 which is right in the middle of the 17 Meter SSB band. If you take that same VXO concept using a 12.96 MHz VXO and mix that with a 6.144 crystal you get 19.104 – 4.9152 = 14.188 MHz – you now are on 20 Meters. A 6.176 crystal gives you 14.22. The 12.96 MHz VXO typically has about a 30 KHz spread so you can have a 60 kHz or more slice of the 20 Meter phone band. All of these crystals are stock computer crystals that typically cost less than 50 cents each. [I used this approach in four different QRP SSB radios and can attest it works!]

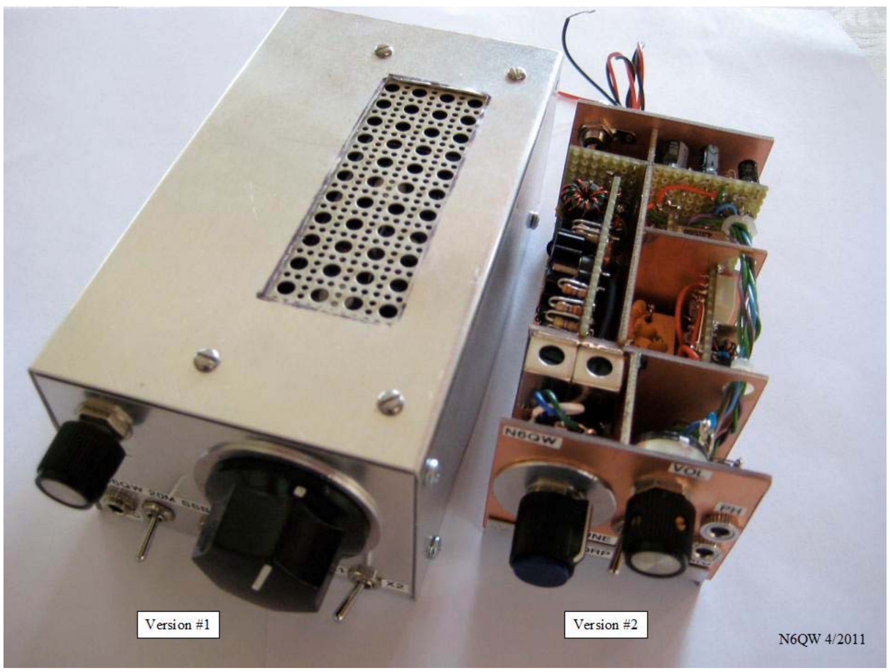
Homebrew crystal filters entail a small amount of effort and this is where the first use of the test oscillator comes into play. For a four pole filter it is a good idea to purchase 10 crystals on the same frequency as you want to find at least 4 that are very close in frequency. You might get lucky and actually get two filters. Of the remaining crystals at least one will be enough off frequency to be suitable for the BFO/CIO. You can use a general coverage receiver to listen to the test oscillator with each crystal plugged into the oscillator. Pick the ones that sound closest in frequency. With a little practice this can be done quite accurately. If your receiver has a digital display it will tell you exactly the frequencies. I happen to have a frequency counter and thus it is a simple matter of reading the frequencies. For a four pole filter you will need 5 coupling caps of the same value. Typically the smaller the caps the wider the filter bandwidth. At around 68-100 PF the filter will be good for SSB and 300 to 470 PF is best for CW. The input output impedance of the filter is in the range of 200 to 400 ohms. I usually assume 200 ohms as it is an easy 4:1 match to 50 Ohms. There are rigorous calculations and simulations that will give you precise values but my empirical “try it and go” is probably fairly close to the calculated values.

A word here about sideband inversion and frequency mixing schemes. Homebrew ladder type filters (the crystals are all of the same value) tend to favor Lower Sideband (LSB). So when you place the Local Oscillator above the incoming signal such as we have with our 17 and 20 Meter example, the subtractive mix of the LO minus the incoming signal results in what is called a sideband inversion. Thus the subtractive mix is on LSB. This is FB because with a filter favoring lower sideband and using a BFO on the LSB

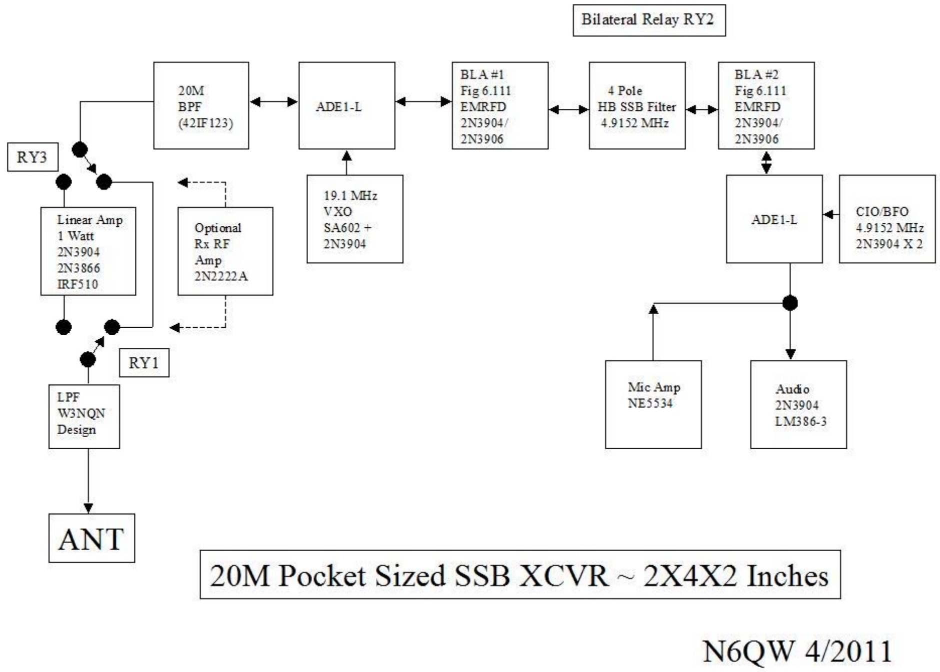
side demodulates the signal as an Upper Sideband (USB) signal. So this is good fortune.

I always like to start a project with a block diagram and then simply fill in the blocks with my favorite circuits. Oh, when I actually build the project I start at the back end and work my way forward. This approach enables me to use the project itself “to test as I build” and should something not work I know exactly where the problem is and do not proceed any further until it is resolved. I should mention that I also have developed standard building blocks that I simply reuse in my projects. I know they work and I know their level of performance.

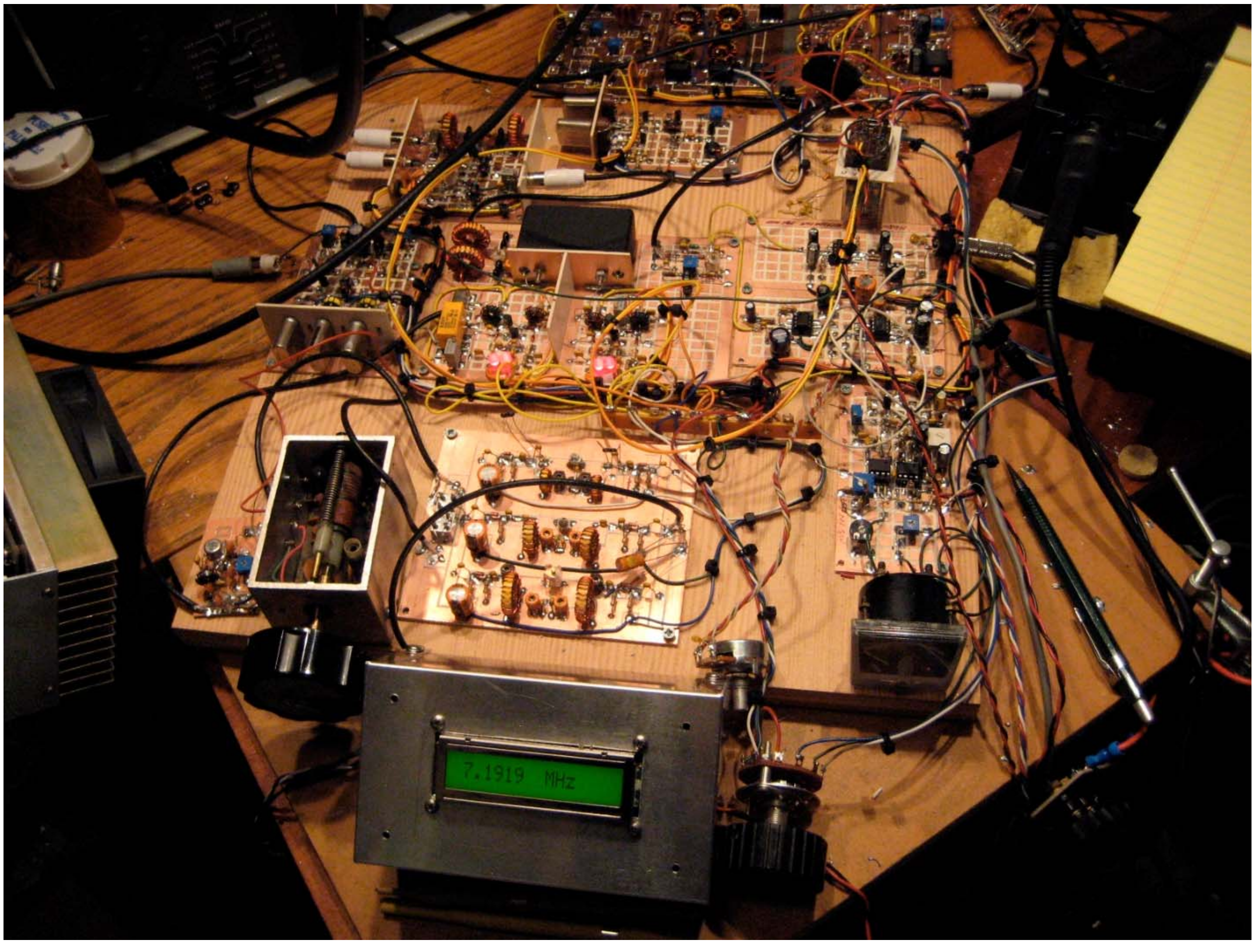
Let us take an example: The next photo is of two transceivers I built which are basically the same circuit with the smaller one being the second build.



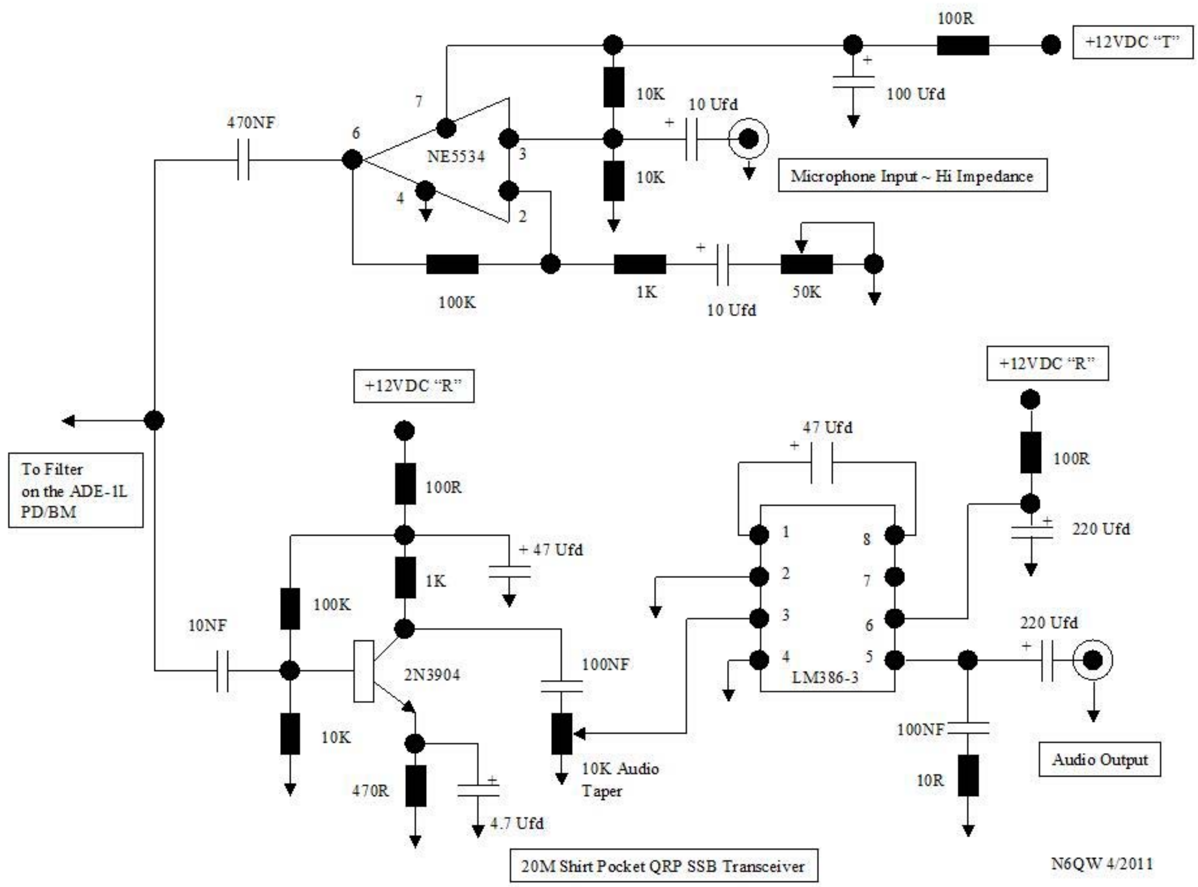
The block diagram for these radio is shown below. The variation between the 1st and 2nd build is the second does not have an Rx RF amp stage and a different RF output stage. These changes were to conserve space and enable making the second one about 1/3 the cubic size of the 1st.



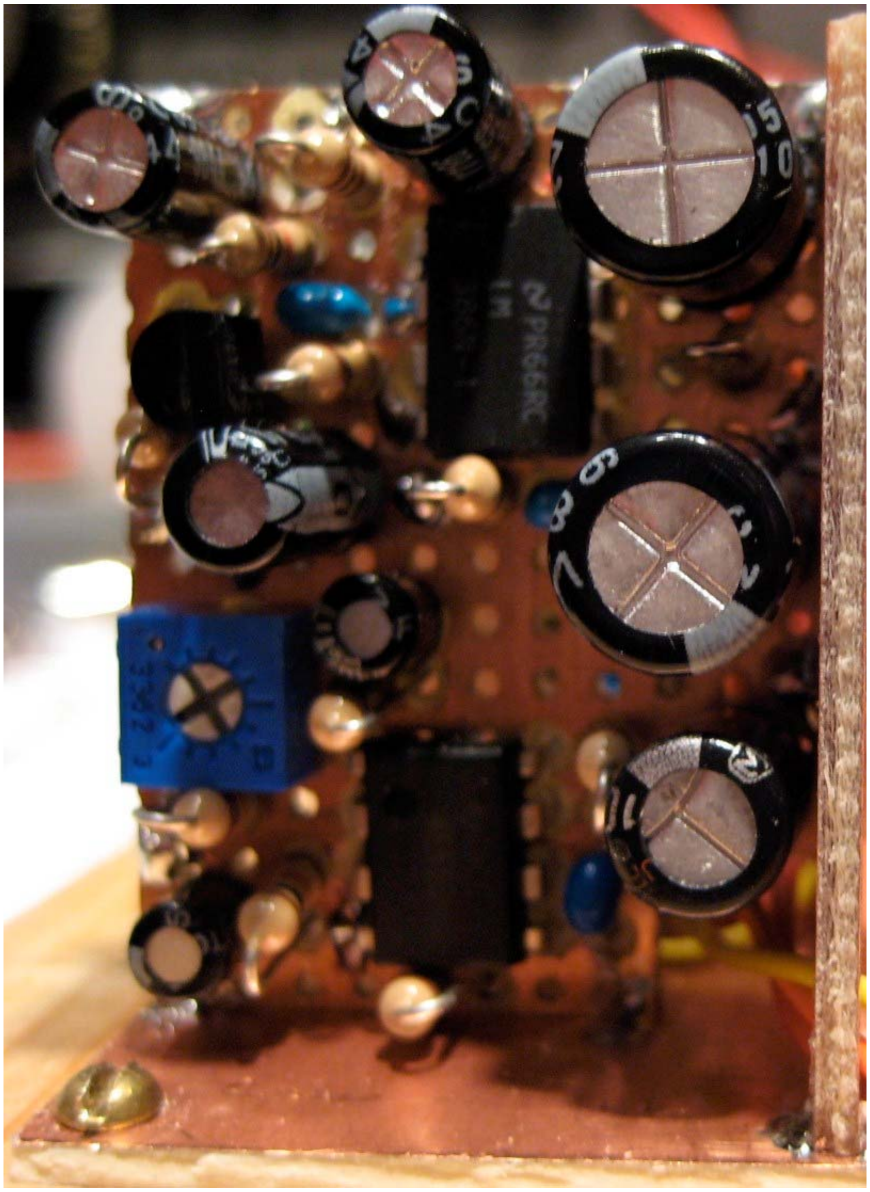
This is a block diagram of a 20 Meter QRP SSB transceiver that could fit in your shirt pocket. Much time was spent on this block diagram in a process I call "noodling", that is thinking about the topology and how to make this an efficient design while at the same time making it physically small. So the first thing to be done is to not heat up the soldering iron but spend some time doing research and collecting information. Once that is done then it is a matter of finding circuits that will work in the blocks. This also is a really good time to think about how the final package will look. I learned that the hard way when I built a tri-band QRP SSB transceiver using the filter and frequency scheme from the Heathkit HW-100. I usually "bread board" all of the radios using a piece of 2' X 2' plywood and that forms the base for temporarily installing circuit boards and thus the radio is tested "out in the open" and then packaged. Here is what the bread board looked like for that project. Once I was at this stage I knew I was in trouble as I hadn't really thought about the final box. Spend some time on this –first. BTW I actually made QSO's with this breadboard radio!



The build process then as previously stated starts at the back end by building the audio amplifier and microphone amplifier stages using designs that I have found really work and involve commonly available parts –no exotic unobtanium parts here! Shown below is the design for these two stages and the beauty is that once built they can be tested and debugged. Thus you know that these are viable circuits and are working!

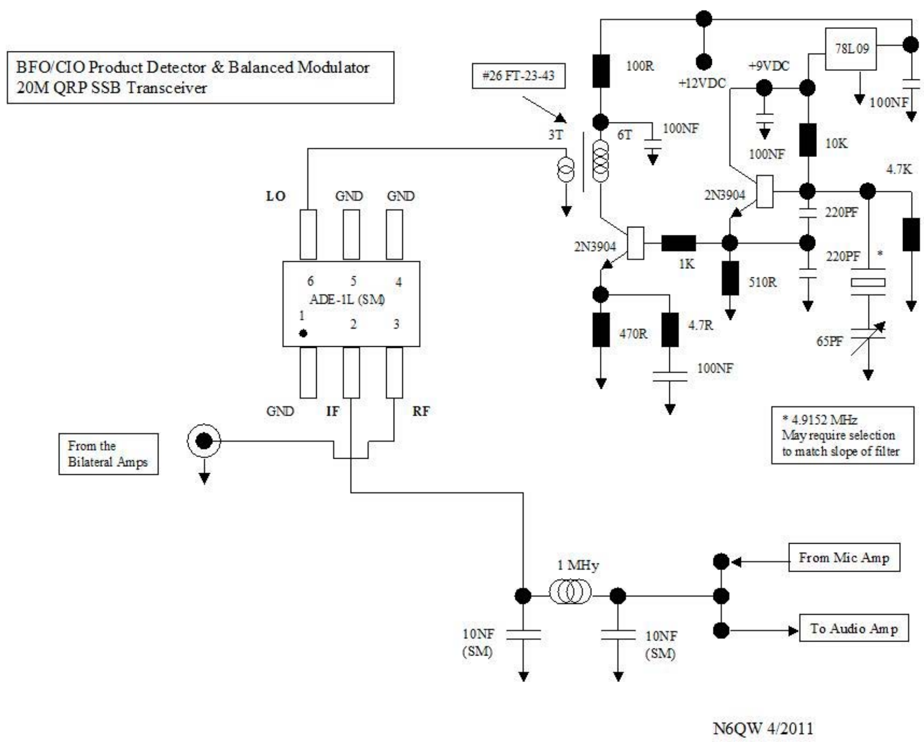


The finished circuit board is shown below and involved the use of single sided copper vector board (read expensive) and was a challenge to build. This board was mounted physically near the back panel of the radio and a 5/16 inch hole was drilled in the back panel so a small screwdriver could be inserted in the hole and aligned with the small trim pot –yes that is the microphone gain control. The only reason I mention this is that front panel space actually dictated the final size and there was no room for a microphone gain control on the front panel. But I had to think about this before I turned on the soldering iron!



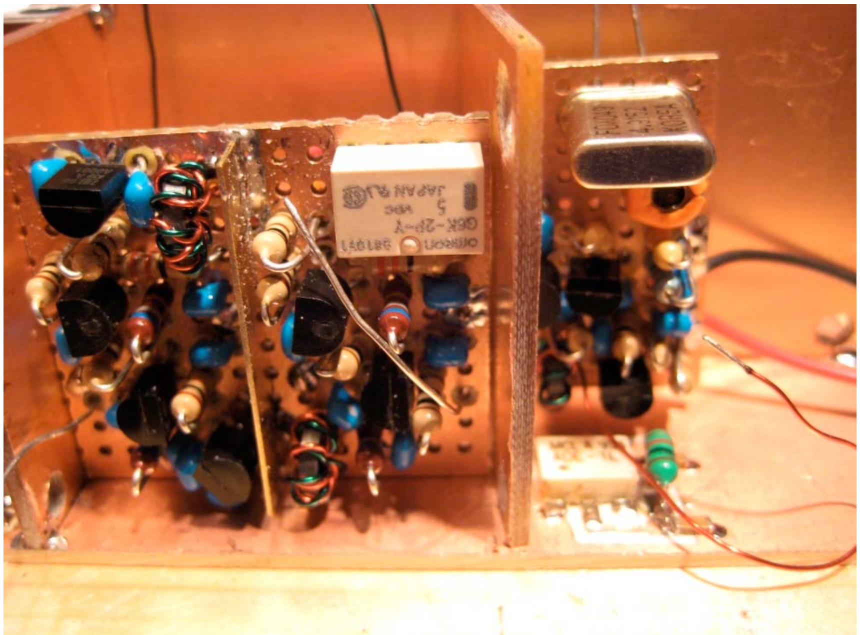
Oh, I have very sophisticated test process for these two circuits. Once built I start with the audio amp and after hooking up power, gain control and a 8 ohm speaker taking a metal screwdriver I simply touch the input pin on the 2N3904 –big hum I know it works. Adjusting the audio gain control should have control of the hum and that the control wires give max gain in the CW direction. Now I power up the microphone amp in addition to the audio amp – using the same procedure –touching the input pin of the NE5534 should result in a loud squeal –adjusting the 50K should show that the microphone gain works.

The next block is the BFO/CIO and combination product detector / balanced modulator. That schematic is shown below. A comment here about the choice of DBM (Double Balanced Mixer) the ADE1-L. It was chosen because it is small, an SMD part, and is a 4 dBm device meaning it only needs 1.0 Volt Pk to Pk to drive it. Here is where some time spent researching can pay big dividends. The ADE1-L is built by mini-circuits labs. At the time I bought these the price for a single unit was close to $16. If you bought three that would be $48. But if you bought 10 the price was under $4 each. So if you bought 12 ($48) that is the same price if you only bought 3. I still have a couple of units in my junk box that are being reserved for the next project!

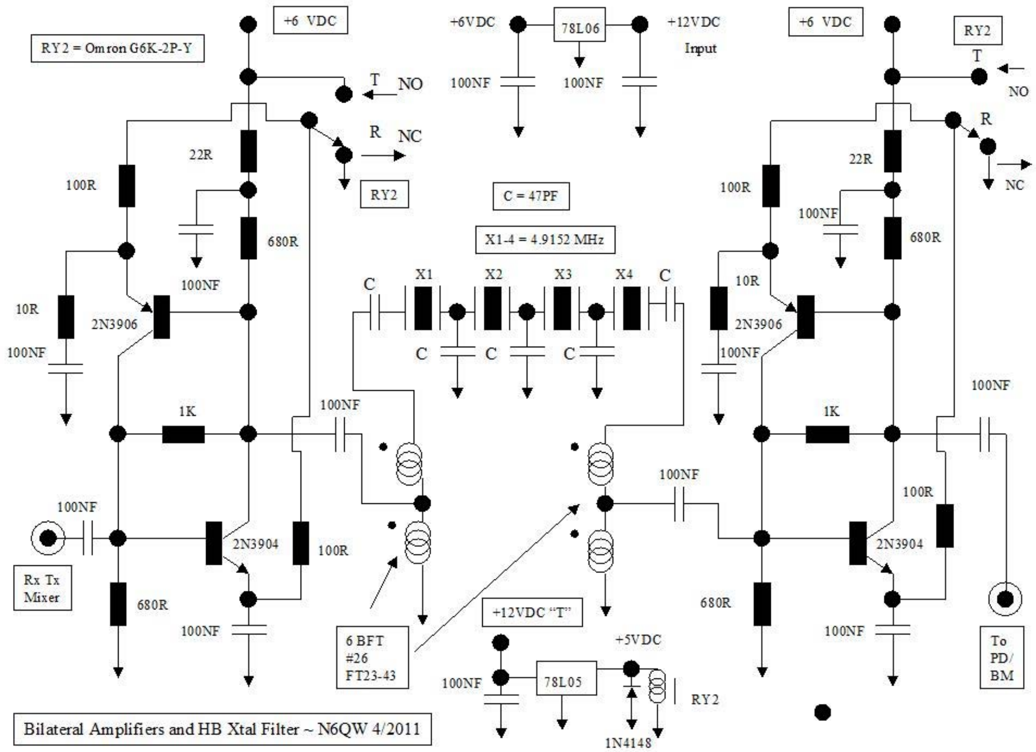


The photo below shows the next two blocks during the construction process with the circuits on the right side being the CIO/BFO and the PD/BM. Once this part of the circuit was built its output was connected to the audio amp module and then using a signal near 4.9152 MHz (nothing more than a one transistor test oscillator tuned slightly off of the BFO/CIO frequency) and then a beat note can be heard coming from the speaker. Now it was clear that these four elements were working. The circuit board on the left side is the bilateral amp stages and behind that the home brew

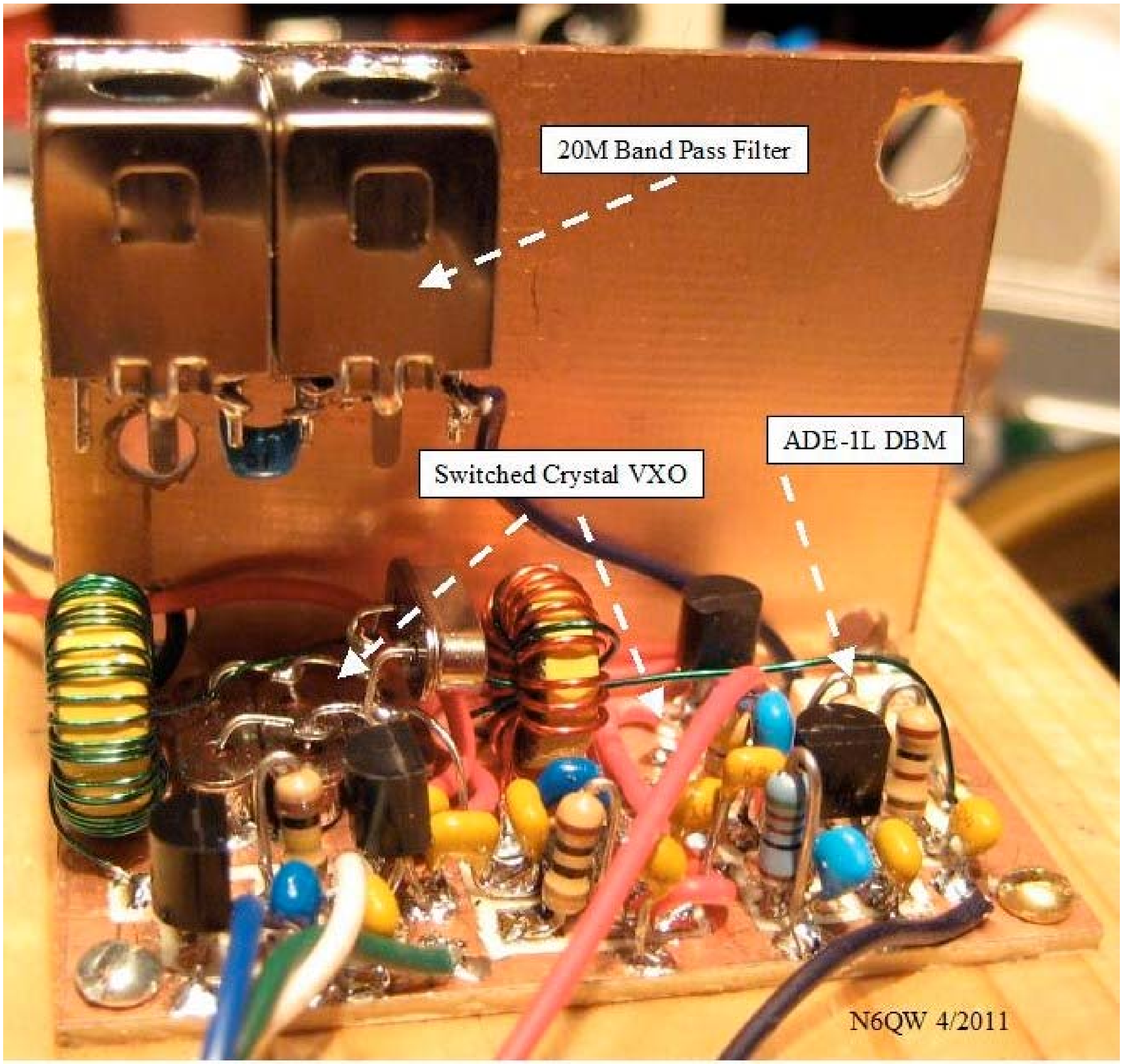
crystal filter. Again the same process of building and then a temporary hookup and test. Using that same test oscillator these two stage and the filter can be checked – as you move the test oscillator through the stages the sound from the speaker should get louder –any stage where it doesn't then you know where the problem is.



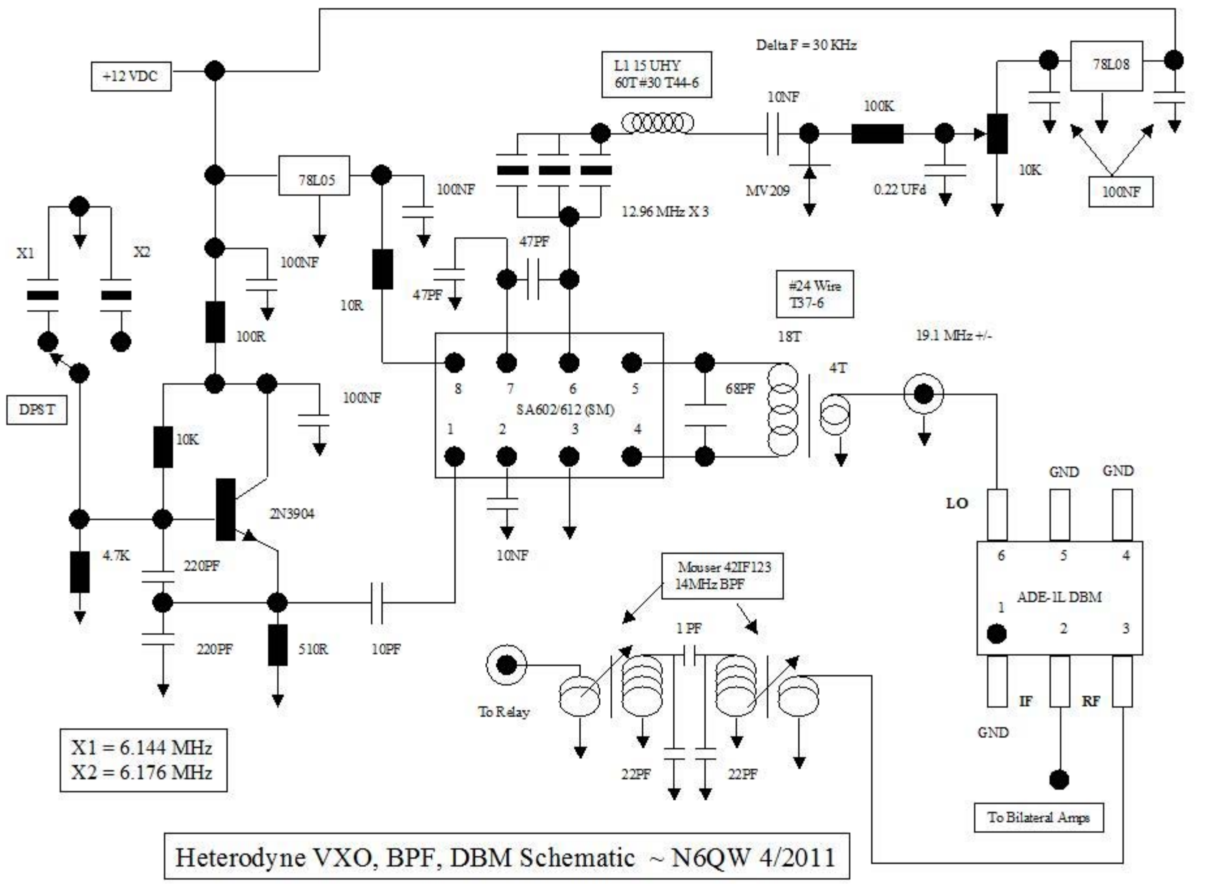
The schematic for the left side is shown below:



The next several blocks, consisting of the Rx Tx mixer, another ADE1-L, the switched crystal VXO and the 20 Meter Band Pass Filter. The width and height is 2 inches so a lot of parts in a small area. Thus the noodling process has to take place first before heating up the iron.

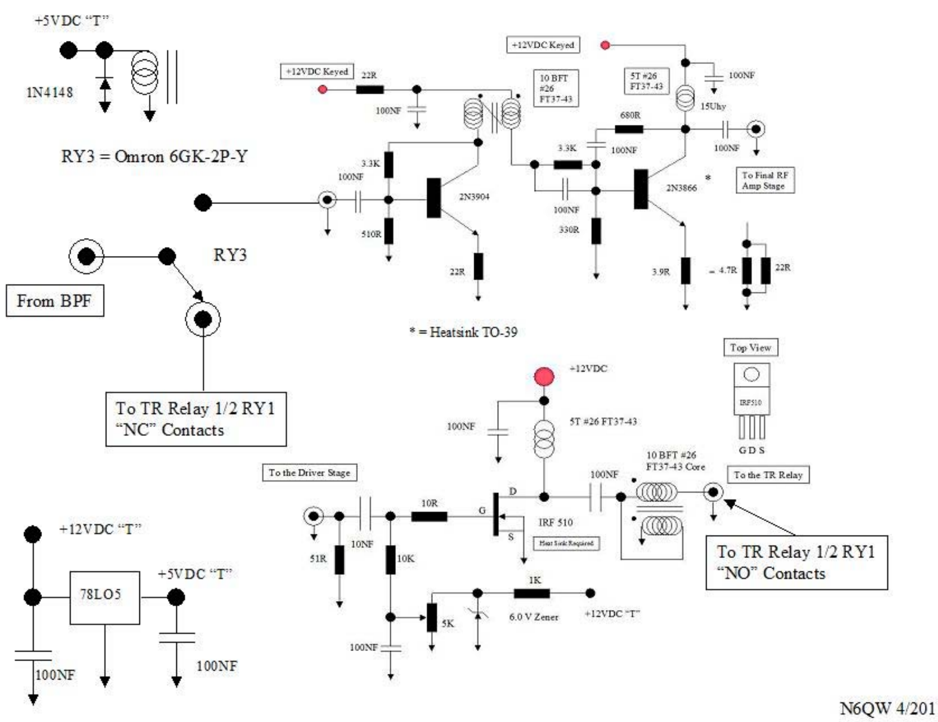


The schematic for this part of the build is shown below. Again these circuits once built can be connected to the already working circuits and the test process here is to inject a 14. 2 MHz signal into the BPF and it should be clearly heard in the audio output.



Spend some time now getting acquainted with the receiver by optimizing the Band Pass Filter for the portion of the band being worked and there may need to be some adjustment of the BFO/CIO frequency so that it is placed on the proper portion of the filter slope. This is also an opportunity to see how well it hears in terms of sensitivity. As the old adage says if you can hear them you can work them. There are several you tube videos which can be found by searching under N6QW and you can hear the two versions of this radio –it hears quite well! The 1st version is more sensitive as it has an RF amp stage but one feature is missing since this project was entirely designed with the idea of miniaturization. No AGC and on occasion really strong signals with the RF amp version WILL overload. Backing off on the audio gain does help. The second version without the Rx RF amp will not overload as much. So adding an AGC would help but that requires more space. PD7SSB on seeing this design added an audio AGC circuit which helps. So that is yet more opportunity for experimentation.

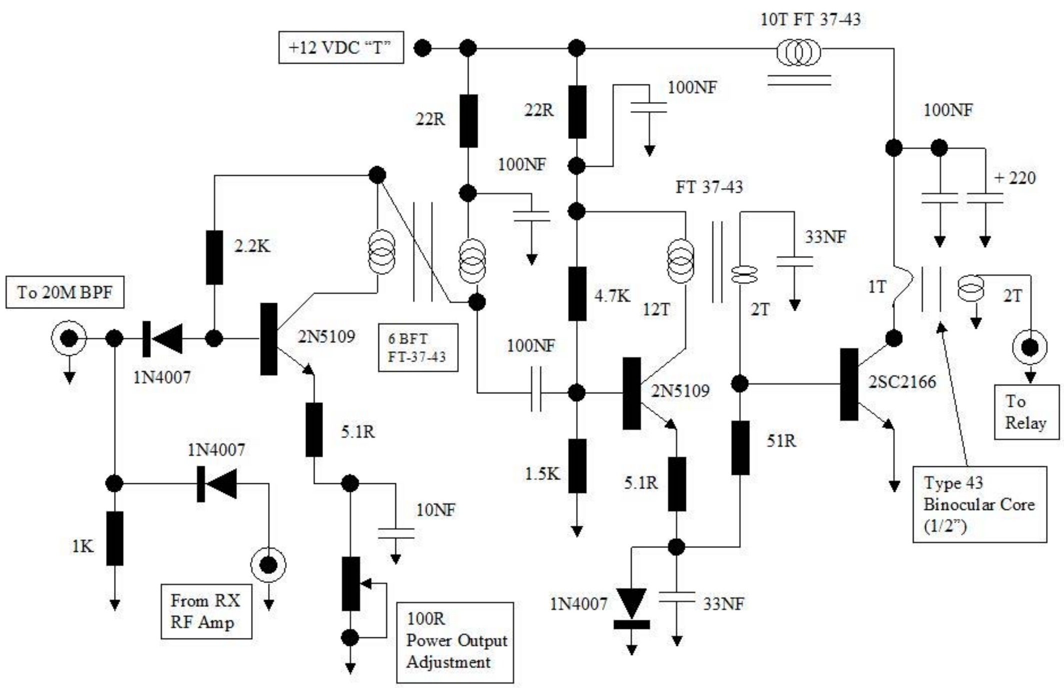
On both versions the circuit black which gave me the most headaches or as some know –heartburn, was the transmitter RF amp stages. This is where one really has to pay attention to circuit layout, unwanted coupling, shielding and heat sinks. In the second version which uses a slightly different “final brick” the problem was heat. The final is an IRF510 and the final bias made it more than warm to the touch –if you wanted max smoke! I tried several of the TO-220 style heatsinks and none were really adequate. Finally I tried using a slab of copper on the back side of the circuit board in addition to the TO-220. In the local hardware store there were heavy duty copper fittings such as are used on grounding cables for house wiring. I found a fitting and smashed it flat in a vise and drilled a hole in the middle to attach to the IRF510. Copper is a much better heatsink than aluminum. Many of the high power RF amplifiers use a copper spreader between the device and the aluminum heatsink –so I just borrowed the idea. The circuits for the smaller version came form EMRFD!



Final RF Amplifier Stage: Source EMRFD Figs 2-93 & 2-98

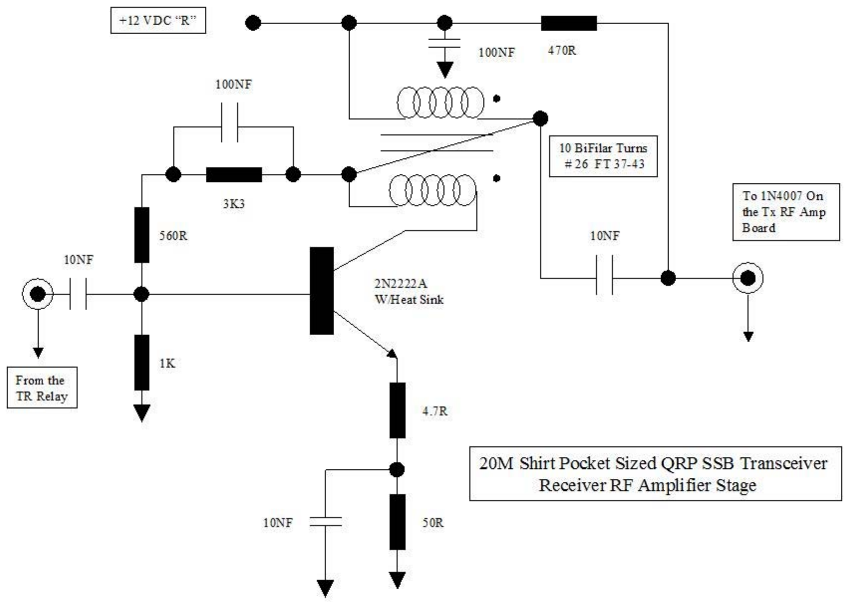
The larger version of the radio used a different RF chain which was physically too big to fit in the space available so it was not used. That said it does produce more power by again the same attention to detail on

unwanted coupling, shielding, and heat sinks was very much the same considerations.



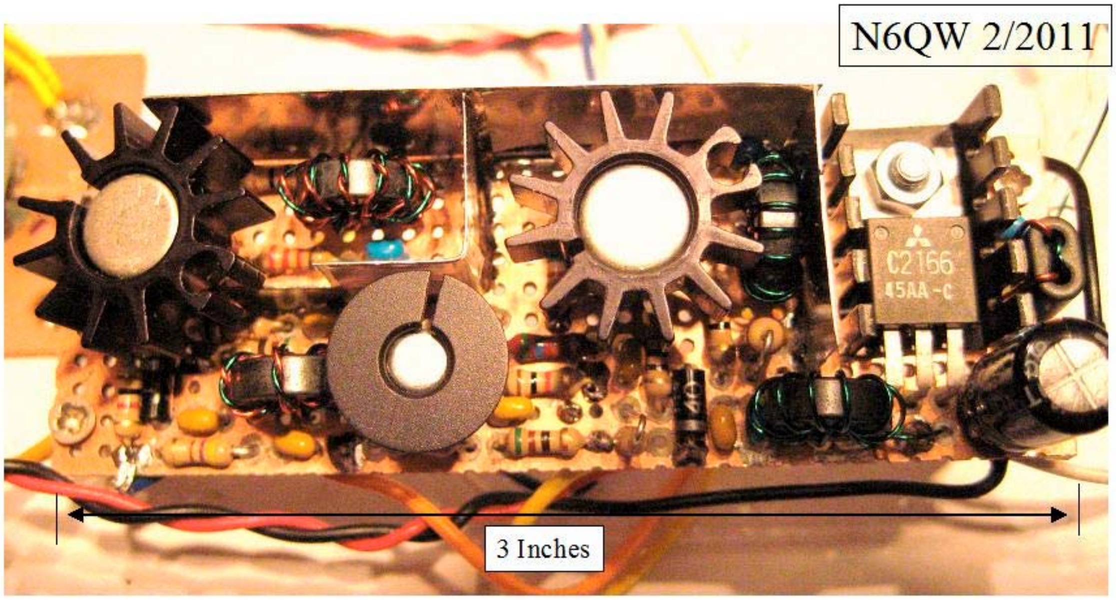
20M Shirt Pocket XCVR Tx RF AMP STAGE
(Rx RF Amp not included on this schematic.)

This version has the Receiver RF amplifier stage and note that diode steering was used to route signals between transmit and receive to/from the common band pass filter network. The 2N2222 is biased "hot" and needs a heatsink. In the photo you can see that the circuit elements are very tight and the use of single sided copper vector board enables a common ground plane so ground loops are not so much of a concern. This approach enables solder shielding directly to the copper surface and it made the task so much easier.



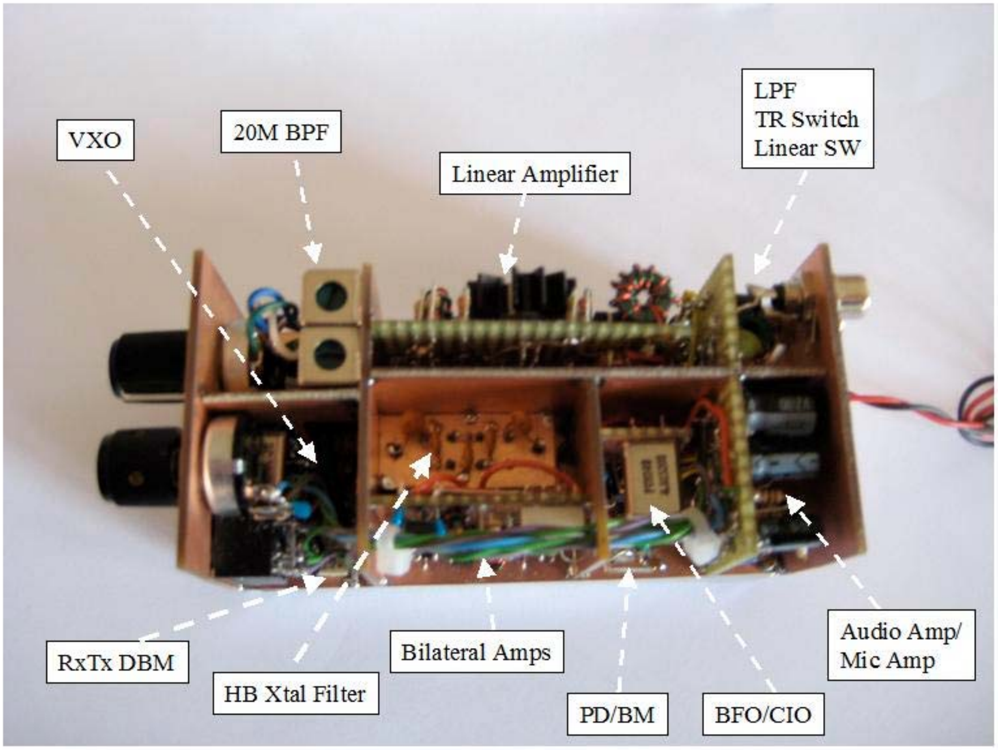
20M Shirt Pocket Sized QRP SSB Transceiver
Receiver RF Amplifier Stage

N6QW 2/2011

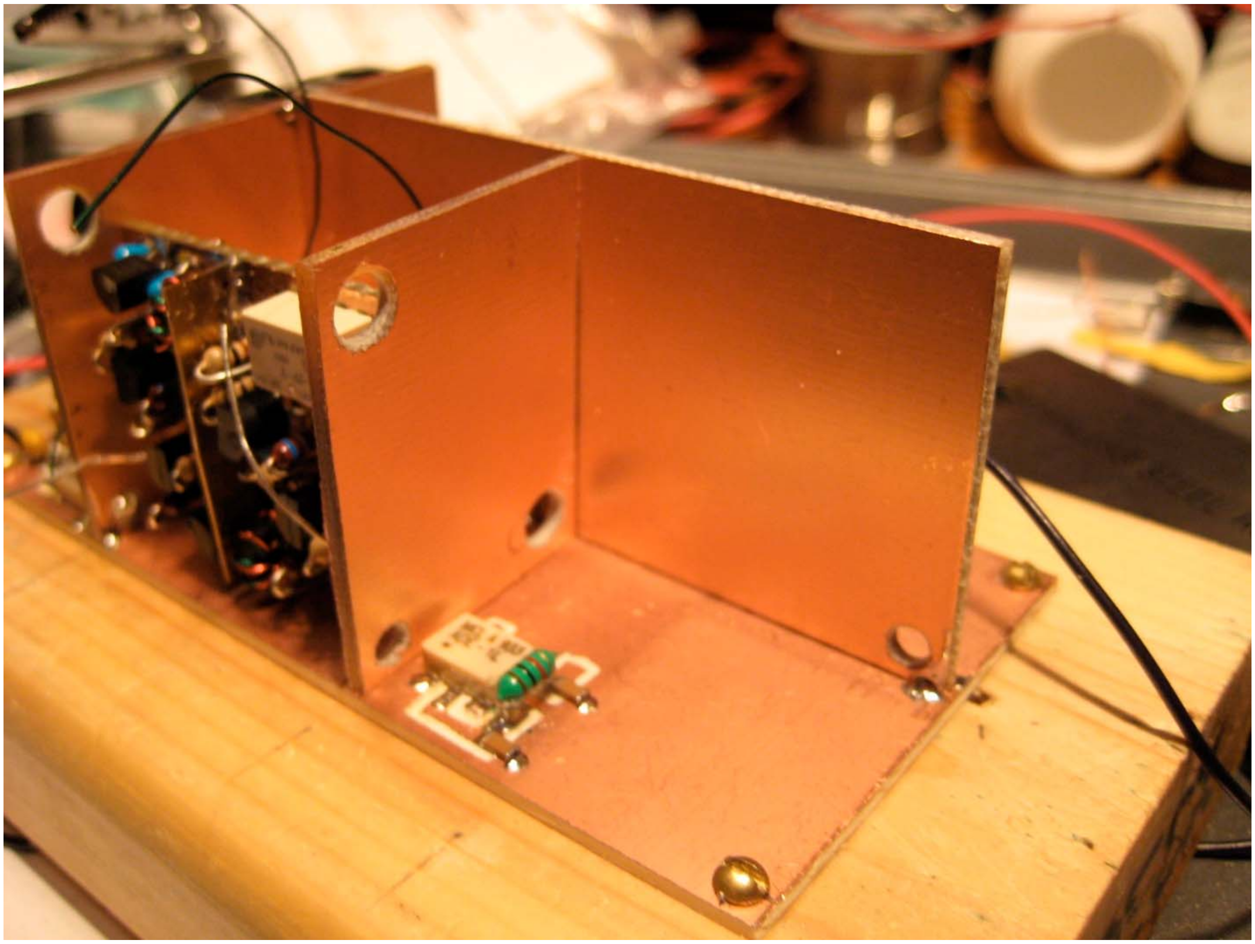


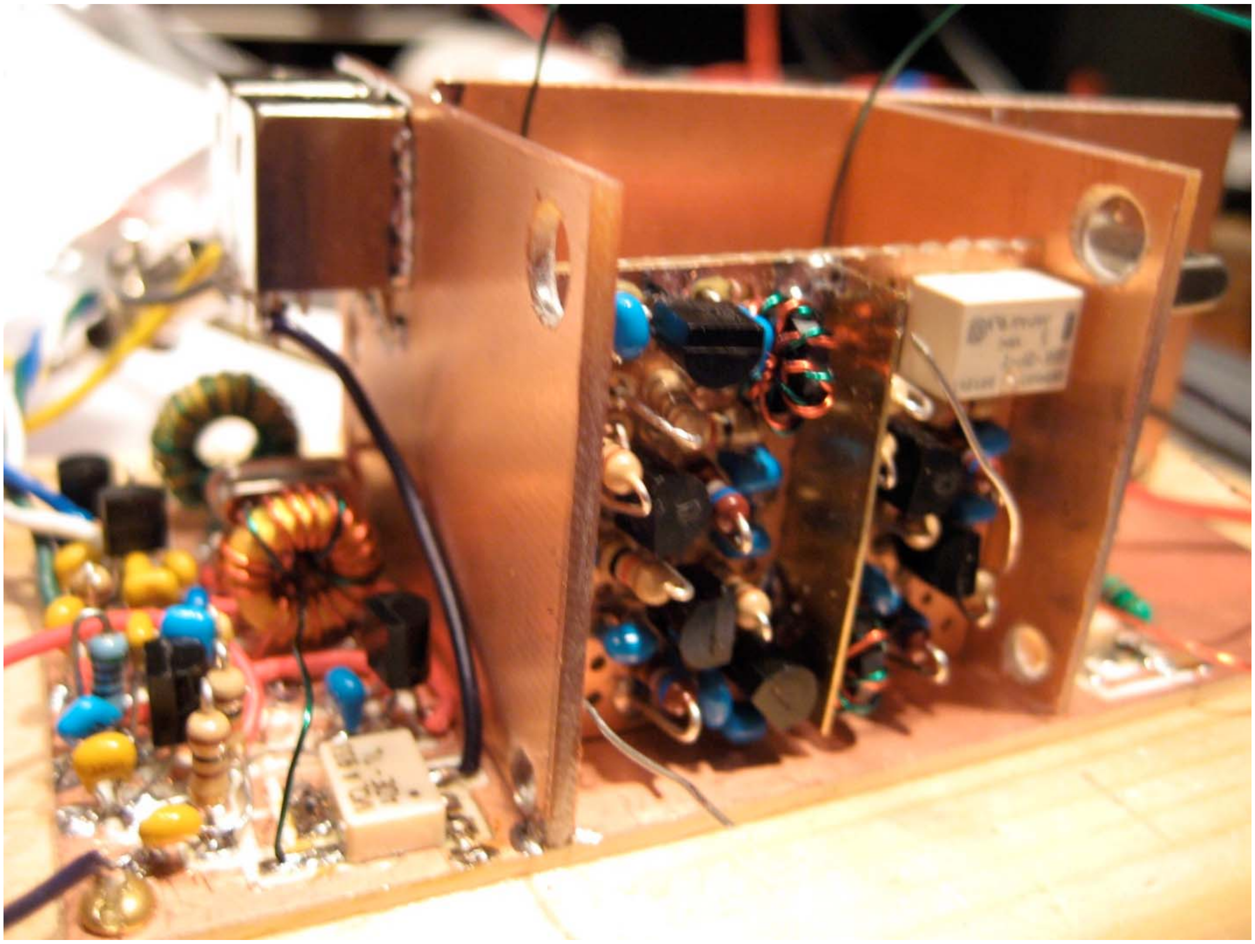
Final Receiver and Transmitter RF Amplifier Board
20M Shirt Pocket Sized QRP SSB Transceiver

A special not here about version two and the concept of a copper “spine’ down the center with many shielded compartments. This is not original work but thanks in large measure to Allison KB1GMX who shared this approach with me. It really works and affords a compact final product with more than adequate circuit isolation and a good deal of surface area to remove heat. Yes some of the circuits do get hot to the touch. In fact in version one after building the enclosure I had to go back and cut a vent hole in the top of the case!



20M Pocket Size QRP SSB Transceiver 2X4X2 Inches ~ N6QW 4/2011





AWSH.ORG

stuff that i do and things that i make

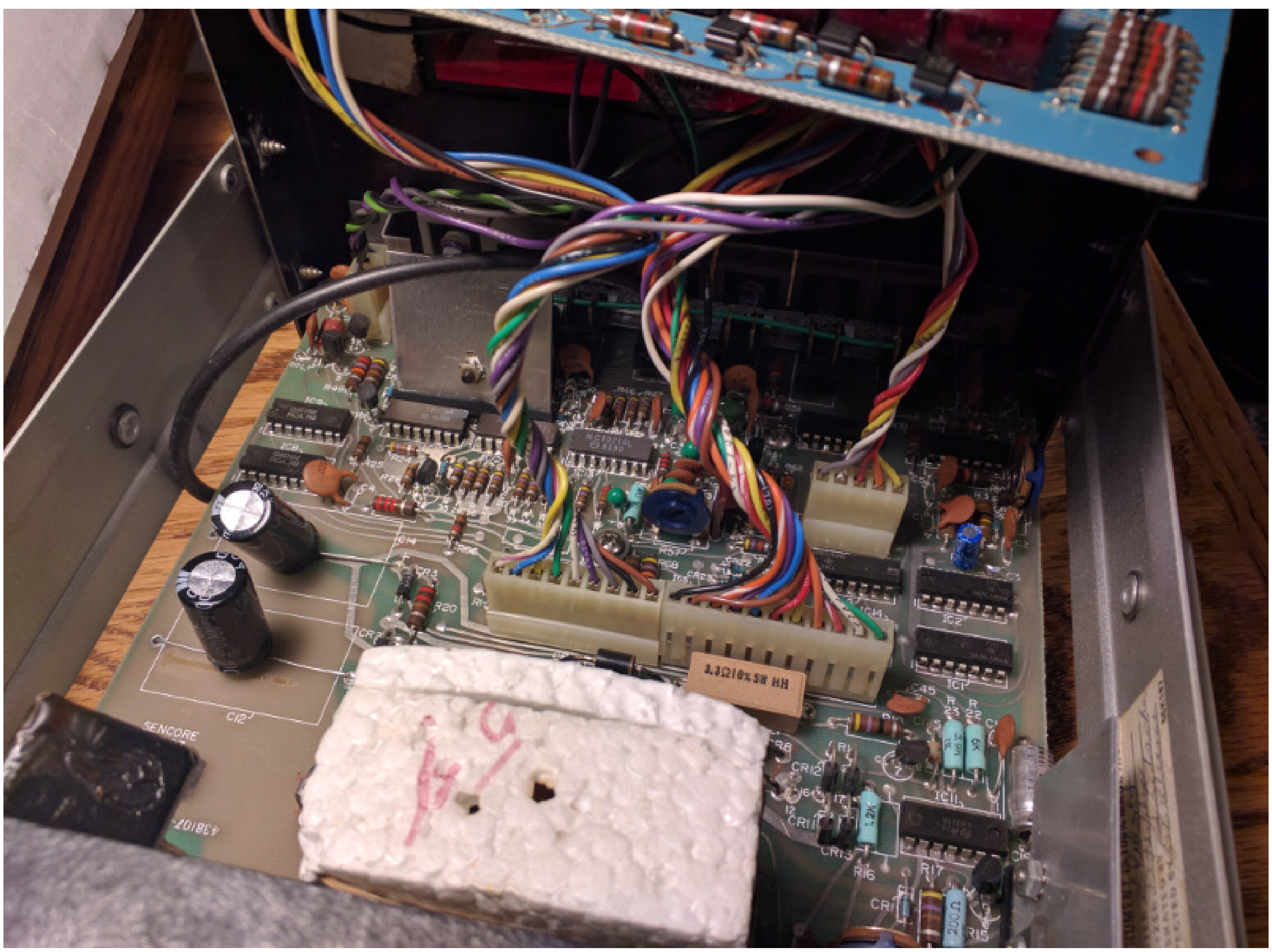
sencore fc45 frequency counter repair

PUBLISHED OCTOBER 9, 2017

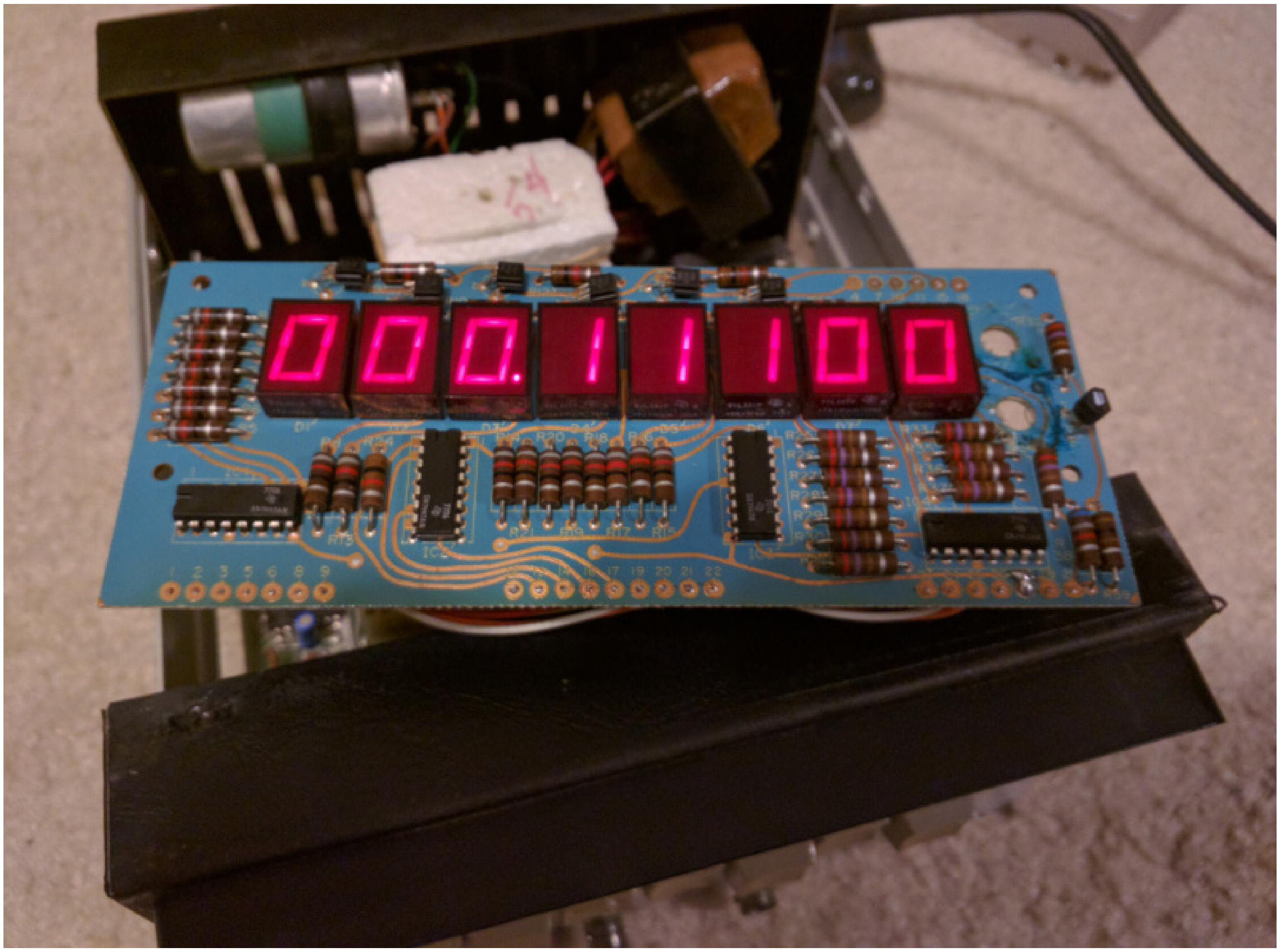
I'm starting to fix up some of the test gear that I recently acquired and first up on the bench is a sencore frequency counter.

The frequency counter appeared to work, but the display wasn't working correctly and the measurements seemed to jump all over the place.

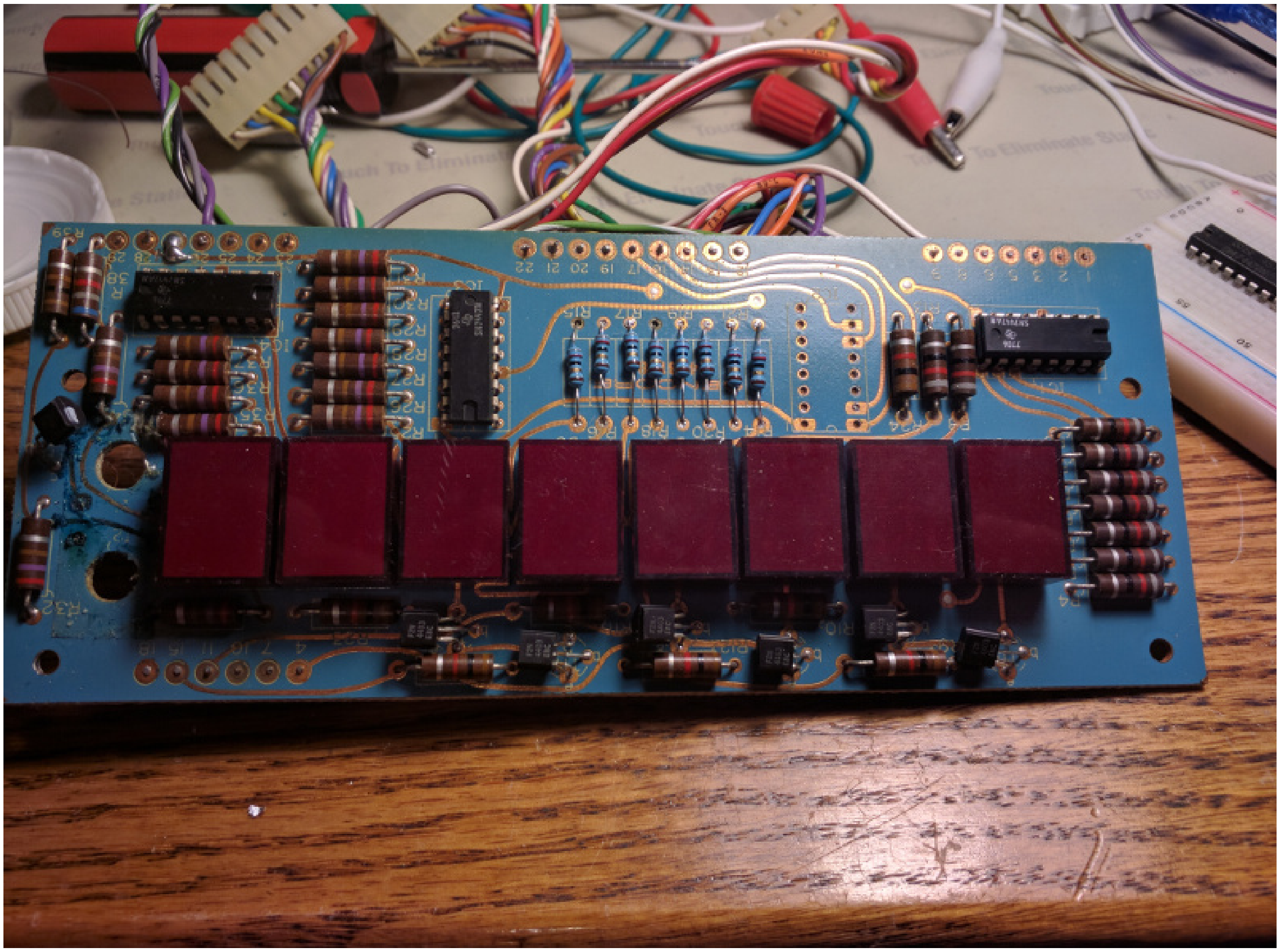
First, I replaced most of the electrolytic capacitors and that seemed to settle down the readings.

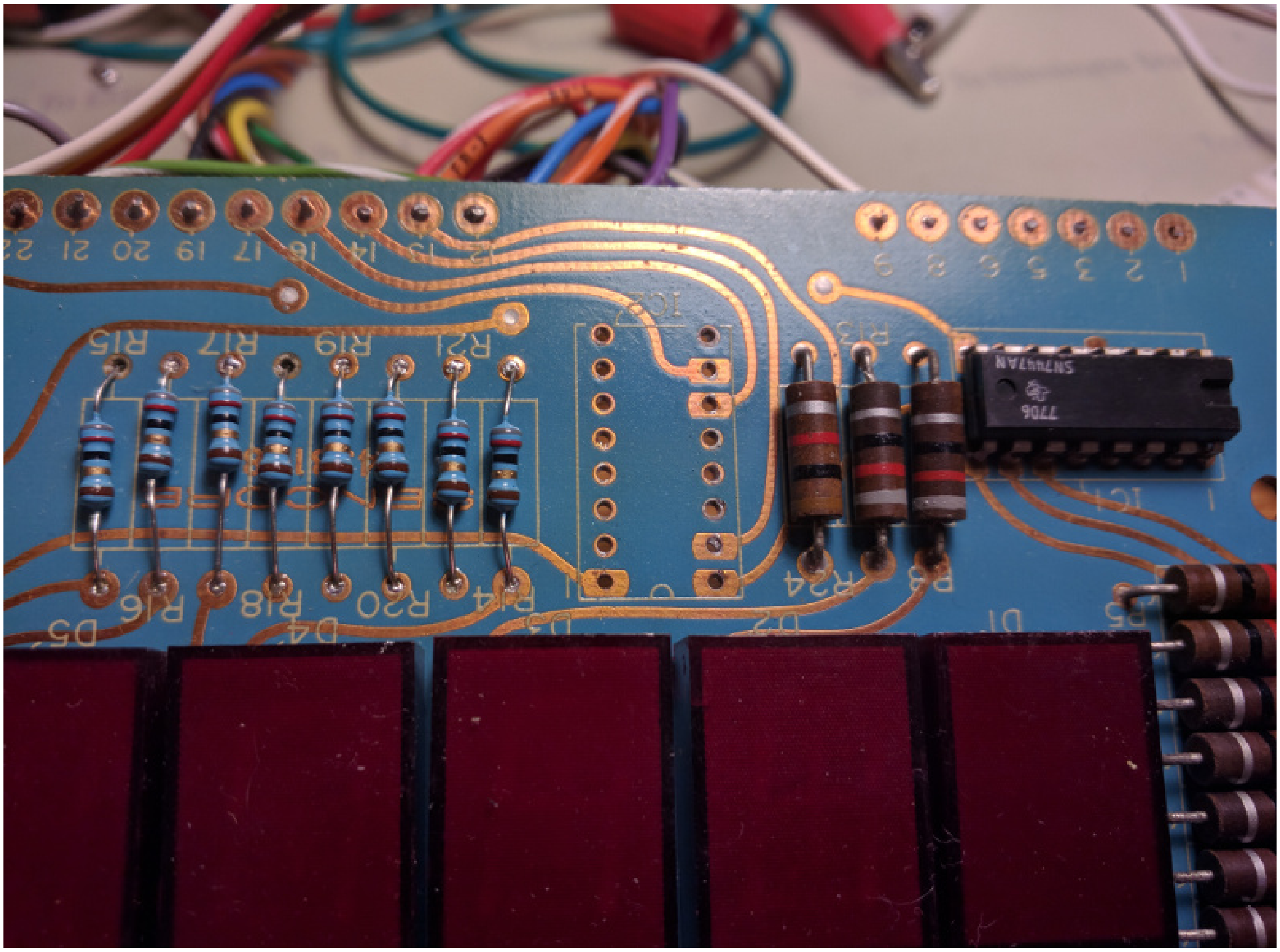


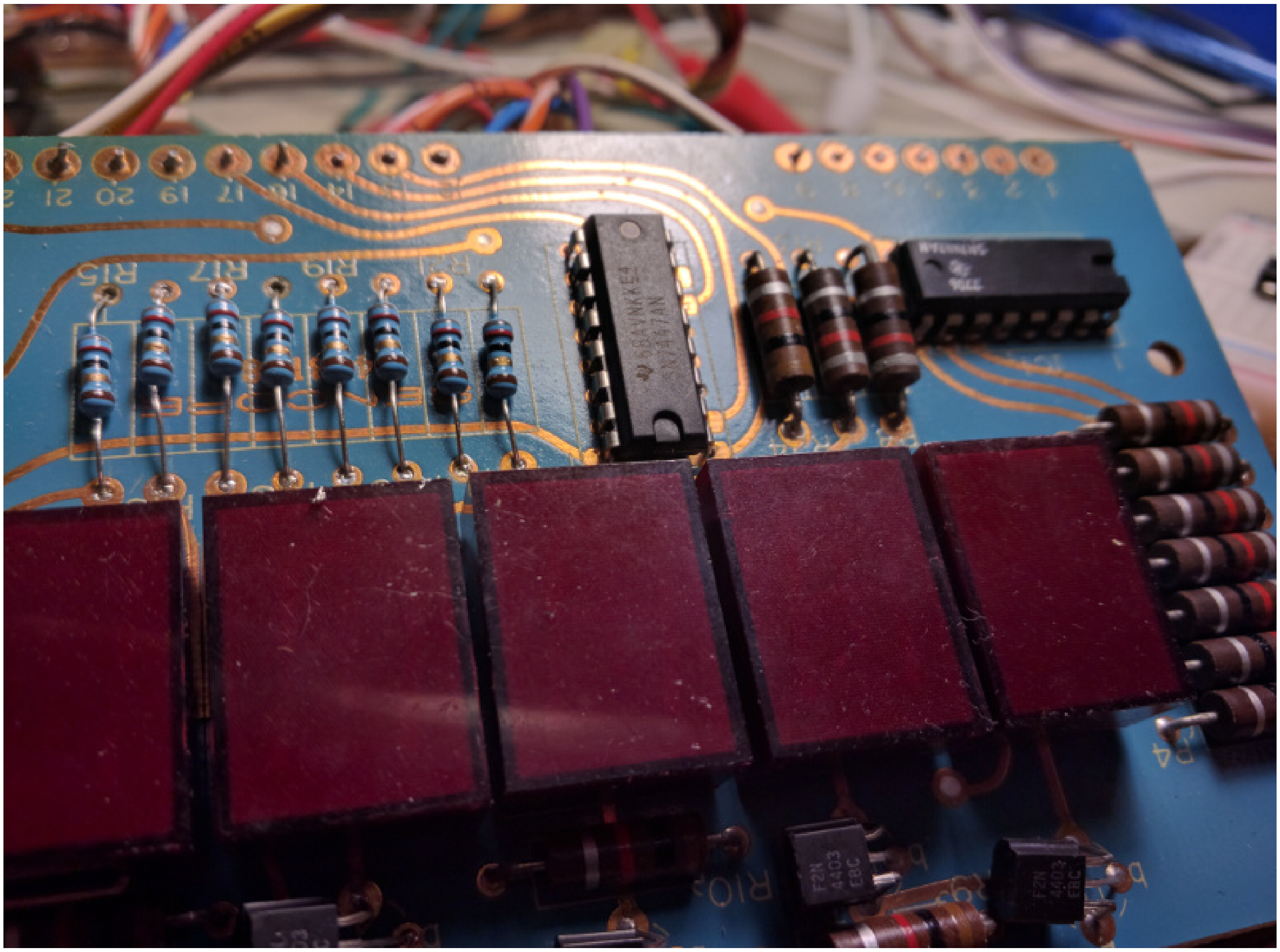
Next, was the display. Four of the seven segment displays were not lighting up correctly. After I cracked it open. I found one of the seven segment displays had a broken trace to one of the leds, so I bridged that and it began working, but as you can see the three in the center still weren't working correctly.

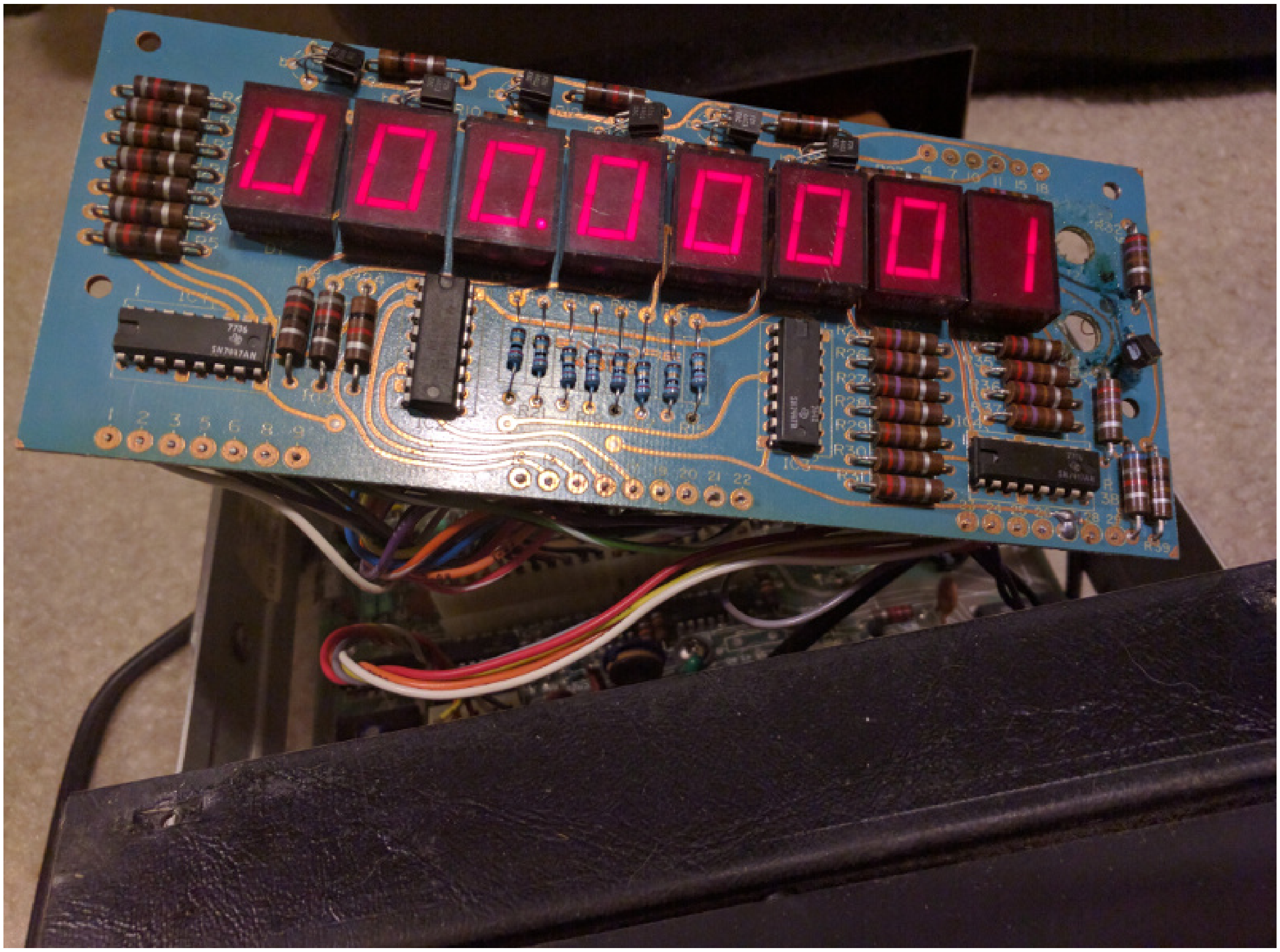


I checked the cathode resistors for those three numerals, and most of them were out of spec, so I replaced them all, but that didn't help. The displays were common anode, so the driver IC should pull each segment to ground, but that wasn't happening, so I ordered a new one. Digikey sent me the wrong part, so it took a little longer than I'd hoped, but I finally replaced the IC.



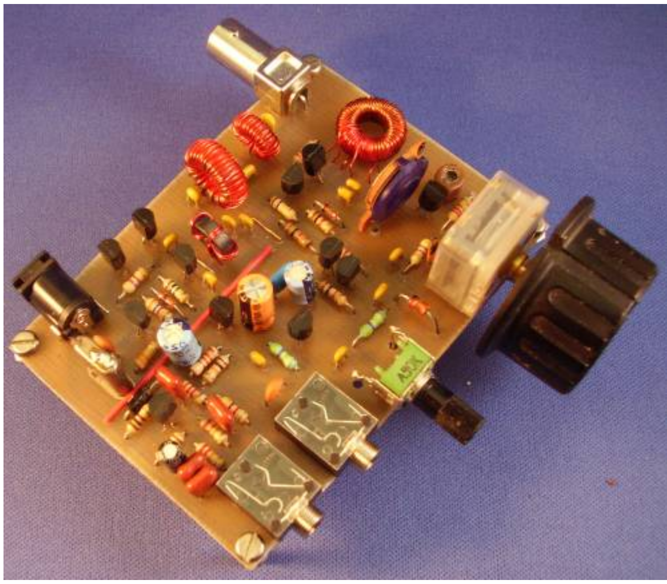






The new IC fixed the display problems and the counter seems to be working well now. I even have the prescaler for it that takes it up to 600MHz.

A Rig for the MAS Contest by KD1JV


Actual size is 3.5" wide and 2.5" deep.

The M.A.S., (Minimal Art Session) is a contest started by Dr. Harmut "Hal" Weber, DJ7ST. (Now a SK)The idea behind this contest is to encourage Hams to build and operate a rig using a minimal number of parts. To be eligible, a transmitter must use no more than 50 parts (pretty easy to do) and a transceiver must use no more than 100 parts (a bit harder to do). To encourage the use of a very small number of parts, bonus points are awarded by the percentage of the actual number of parts used less than the maximum allowed number. Thankfully, things like hardware, knobs, connectors, headphones, key and the like are not counted as parts. Also, the transmitter low pass filter is considered to use 3 parts, even if in actual fact it uses more parts to ensure spectral purity of the transmitted signal.

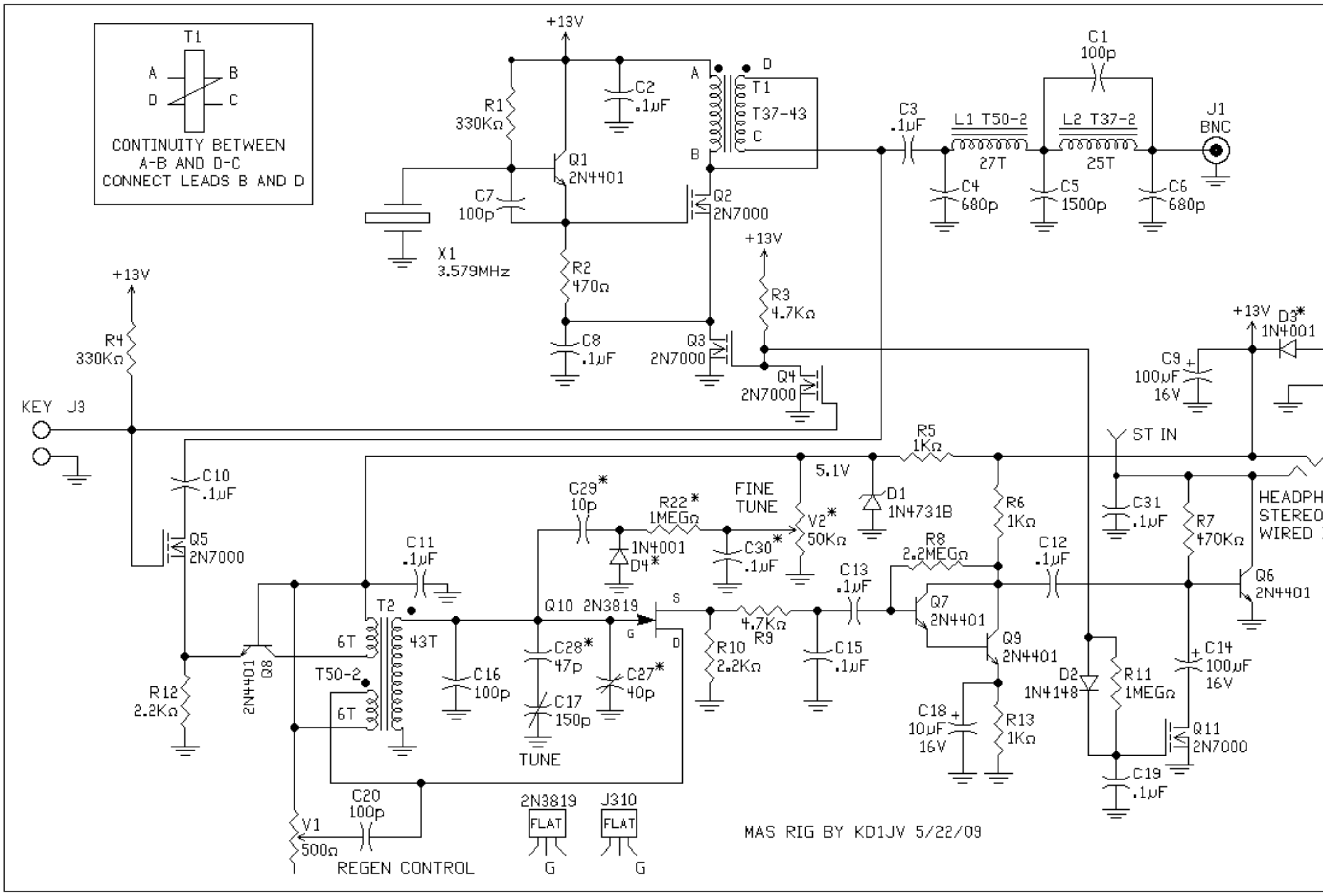
However, if you use any IC's, the number of parts integrated into the IC must be counted. It is impossible to determine how many resistors, transistors and diodes (capacitors are usually not integrated onto a chip, but sometimes there can be) are inside a chip since the manufacture usually does not bother to tell you and if there is a simplified diagram of the insides, it does not show all the parts. And even if this number can be determined, even a simple IC can have dozens of parts integrated. So, this effectively eliminates the use of any modern IC's in a rig designed for the MAS contest. Not being able to design with op-amps, audio amps like the LM386, mixers like the SA612 or CMOS logic gates, is a definite handicap to designing a simple, but effective rig which is actually capable of making contacts.

Despite the limitations of not using IC's as noted above, I decided to give it a try. Some very simple and very low parts count rigs have been devised over the years, one of the most well known is the "Pixie". The problem with these overly simplistic designs is they simply do not work very well. The chances of actually making a contact with one of these rigs is slim to none. In my opinion, they are a waste of time and of natural resources. What good is a extreamly low parts count rig if you can't make contacts with it? If I am to spend time and effort to design and build a rig, I want something which at least has a good chance of actually talking to someone! If your gonna work a contest, you got to be able to hear people coming back to you!

The rig I came up with uses 51 parts for a complete transceiver, giving a 50% bonus. The transmitter puts out about 2 watts, the only supr is -50dBc at the second harmonic, and uses just 16 parts. The receiver is a regenerative type detector, with a RF pre-amp and two stage, high gain audio amp, for a total of 35 parts in its minimual configuration. MDS is about 0.5 uV if you have good hearing. Since the MAS contest is an 80 meter event, this rig is designed for 80.

Optional Parts: Parts marked with a "*" on the schematic below are optional parts. These are D3, a reverse polarity protection diode and a fine tuning control. Since the rig does not produce a side tone on its own, an optional side tone generator is also described. These parts are included in the printed circuit board layout to make the rig more useable in general use.

The Schematic:



The transmitter:

The transmitter is a simple crystal oscillator using a 3.579 MHz color burst crystal. A 2N7000 MOSFET is directly coupled to the output of the oscillator for the PA. Q3 is used to key the oscillator and PA on and off. Q4 is used as an inverter so that normal, active low keying can be used. Rise and fall time wave shaping is not included to reduce parts count, so this circuit will produce key clicks. C7 provides feedback so the circuit will oscillate. Normally, a second capacitor would be used from the emitter to ground, but the 2N7000 has enough gate capacitance to eliminate the need for that additional cap. Instead of the normal sine waves one would expect from a crystal oscillator, this oscillator was made to produce fairly narrow pulses. This improves the efficiency of the PA so that even though the 2N7000 is in a plastic TO-92 package, it does does not get alarmingly hot producing 2 watts of output. It is advisable the antenna load be preset to a low SWR before transmitting, as the 2N7000 has a 60V break down voltage and a high SWR can easily exceed this, causing the part to fail. The output low pass filter provides some impedance matching between the output of the PA and the antenna load. C1 in combination with L2 forms a trap at the second harmonic, other wise an additional filter stage would be required to meet FCC spectral purity regulations. Instead of buying a single 1500 pfd cap for C5 in the LPF, two 680 pfd caps could be used instead.

T1 is a bifilar wound transformer, which means two wires are wound around the core at the same time. (5 turns). Use an ohm meter to determine the ends of the wires A-B and C-D, then connect the ends B and D together to form the center tap, as shown in the diagram in the schematic.

The Receiver:

The receiver is a regenerative type and is a slightly modified version of the QRPKITS "Scout" regen designed by Charles Kitchen. See http://www.qrpkits.com

Q5 is the QSK switching transistor. During transmit, this transistor is turned off to isolate the receiver input from the low pass filter. Q8 is a common base RF pre-amp to keep the oscillations from the regenerative detector from being transmitted and reduce pulling effects from the antenna. The resonant circuit made up of the secondary of T2 and C16 determines the operating frequency of the receiver. Ideally, the tuning cap C17 should be an air variable with vernier drive. If you don't mind adding a few additional parts, a pot tuned varactor diode can be added for fine tuning and a small value trimmer cap (C27) used to help set the tuning range. Making C16 150 pfd and using a 50 pfd tuning cap (jumper out C28) allows for pretty much full coverage of the 80 meter band, so a vernier dial is needed or the tuning is very touchy. The schematic is drawn showing the use of a polyvariable capacitor with the varactor fine tuning. Polyvariable caps are also available from qrpkits.com.

Stability of the receiver is directly related to the stability of the input tuned circuit. NPO or C0G type caps should be used and an air variable for tuning. Using a powdered iron core for the inductor is a liability, but an air core coil would be much larger and more difficult to manage physically.

In order to receive CW or SSB signals, the regenerative detector must oscillate. A feedback winding on T2 turns the circuit into an oscillator. V1 in combination with C20 is used to control the amount of feedback. Polarity of the feedback winding is important. If you can not get the detector to oscillate, reverse the feedback winding connections. When winding T2, wind the 43 turn primary first and leave as much of a gap as possible between the start and finish of the winding to have a place for the two 6 turn winding to fit onto. Then wind the two 6 turn windings next, continuing in the same direction as the primary turns. Now, pick on end of the 43 turn primary winding as the "hot end" connected to the tuning caps. The start of the 6 turn winding next to the end of the 43 turn winding should go to the j-fet and the other end to the 5.1V supply. The polarity of the winding going to the RF pre-amp does not matter, so you can pick either end for those connections.

Ideally, the regen control is set so that the detector just starts to break into oscillation. This gives the best selectivity and sensitivity. However, this point will change when returning the frequency for receiving, so in practice, set the control so oscillation is sustained over the tuning range.

R9 and C15 form a low pass filter to eliminate high frequency audio and any RF which is present on R10. Note that the drain and source terminals of a J-FET are symmetrical, so they can be interchanged. That is why the schematic looks different from the way it might normally be drawn. Q7 and Q9 form a high gain darlington amplifier. Q6 further amplifies the audio and has the headphones connected in series with the collector, so it is acting as a Class A amp. Doing it this way eliminates the need to make an amplifier which can drive a low impedance load and saves a significant number of parts. NOTE: The mounting sleeve of the headphone jack is connected to the power supply, so must be insulated from a metal front panel!

Keying the transmitter without any kind of audio muting circuit resulted in very loud clicks in the headphones. This was clearly not acceptable, so a mute circuit had to be devised. This resulted in adding R11, C19, C14, Q11 and D2. When the transmitter is keyed, Q4 is turned off allowing R3 to pull the gate of Q3 high, enabling the transmitter. D2 allows the gate of Q11 to also be pulled high, turning Q11 on and connecting C14 to ground, which by-passes the base of Q6 to ground. When the transmitter is un-keyed, the RC time constant of R11 and C19 delays the turn off time of Q11 to allow any voltage transits to dampen out and eliminates serious clicks from being heard. Some minor clicking is still audible, but it is of reasonable level and not at all annoying.

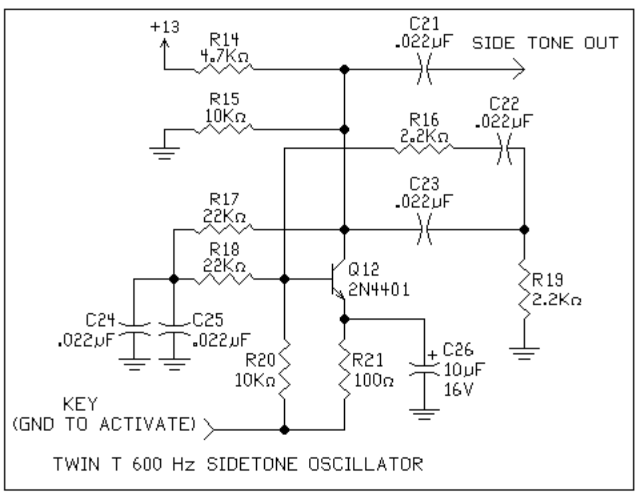
A 5.1V zener, D1 stabilizes the voltage to the RF pre-amp and regen detector. If no reverse polarity diode is used to save a part, one must be careful to observe correct polarity when connecting up power. Powering the rig with a regulated 13.8V supply is recommended, although a 12V gell-cell can also be used, though that might result in chirp, as the supply to the oscillator is not regulated. Minimum operating voltage is about 10 volts, with the power output dropping off to about 500 mw.

Note that a regenerative receiver is effectively a direct conversion receiver, so signals on both sidebands will be detected.

Since one will normally be using the receiver for CW or SSB it will be in the oscillating detector mode. There is enough RF signal present on R10 to add a sensitive frequency counter for a digital readout. This fact could also be handy in initially getting the receiver to tune in the desired frequency range. A frequency counter or a general coverage receiver can be used to help set the tuning range. I tried to make the crystal oscillator act as a "Spot" so you could tune to the transmitter frequency. However, the signal is too strong and blocks the receiver. A separate, outboard oscillator maybe made to provide a spot frequency.

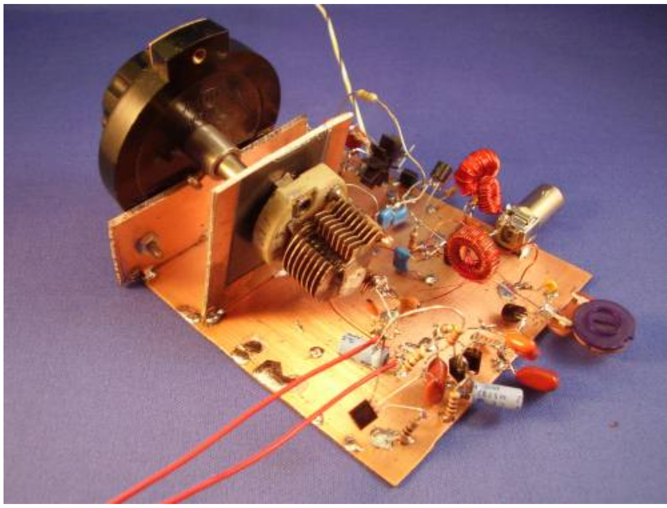
DSB transceiver possibility! It could very well be possible to buffer the carrier signal produced by the regen detector and use it to drive a balanced modulator to produce DSB (Double Side Band). The output of the modulator would then be amplified by some linear amps for transmit. This could result in a very low parts count DSB phone rig!

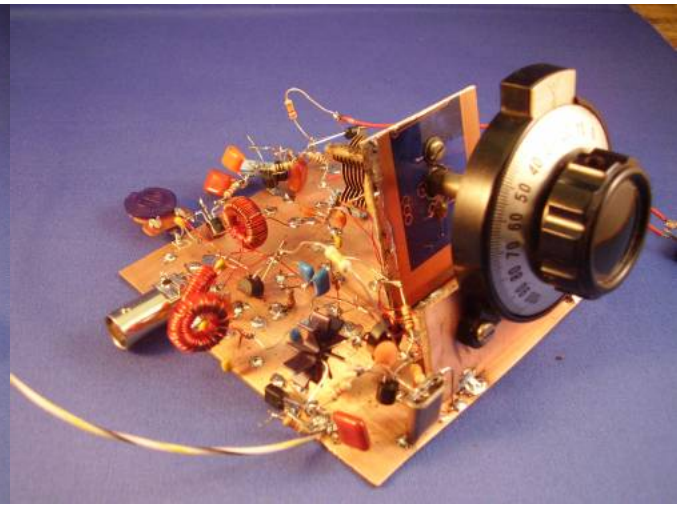
Side tone generator:



The above "Twin T" 600 Hz side tone oscillator is included on the circuit board. If you have a keyer which can generate it's own side tone, these parts can be eliminated. The "side tone out" connection goes to the point labeled "ST IN" on the main schematic. C24 and C25 can be combined as one 0.047 ufd cap. Film type caps should be used for C21 to C25.

Pictures of the dead bug constructed prototype:(but is missing the audio mute parts, as these were added after the photos were taken) These photos prove it doesn't have to look pretty to work! A small finned heat sink was used on the PA in this version so that prolonged keydown periods could be done while testing.



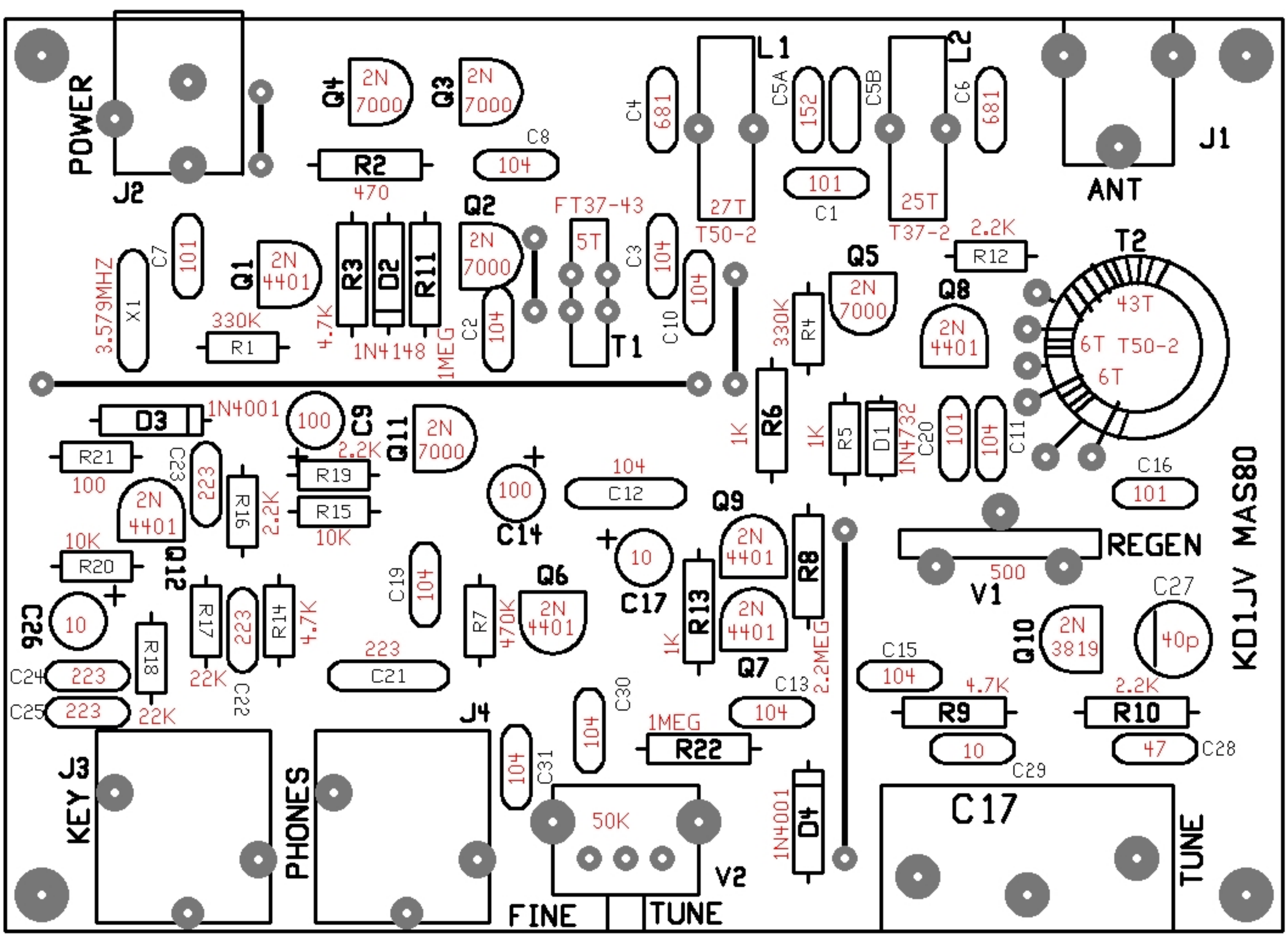


PCB Construction and parts list:

The printed circuit layout can be down loaded by clicking HERE. It is a .pdf file and will print to scale. The view is through board, so it can be printed directly onto toner transfer film. The image is reversed when you iron the pattern onto the board.

Parts subsitution:

I used 2N4401 NPN transistors, as I have a lot of them. Other NPN's such as 2N3904 or PN2222A should work as well. The J-FET I used is a 2N3819, but other N channel J-FETs such as the J-310 can also be used. Note however, the position of the gate lead is different in most other J-FETs, as shown on the schematic. The diode used for varactor fine tuning is shown as a 1N4001 on the schematic. I used a 1N4753B, a 47V zener diode. The 1N4001 may result in a smaller tuning range and C29 may have to be made larger in value to compensate. A red LED also makes a good varactor diode. The Main tuning range is about 200 kHz, from 3.5 MHz to 3.7 MHz. If you want increased range, make C27 larger in value and compensate with the trimmer cap to put the tuning in the band. Values used in the side tone oscillator should not be changed, as this will change the oscillator frequency. Also, the values used in the transmitter low pass filter need to be as shown. You do have some leway in the other resistor values, going +/- one 5% step should not be a problem, though common values are used.



INSTALL JUMPERS BETWEEN PADS INDICATED BY BLACK LINES.

Q1	2N4401	NPN	R1	330K 1/4W 5%	C1	100p C0G
Q2	2N7000	T-FET	R2	470	C2	0.1 ufd X7R, 50V 0.1" ls
Q3	2N7000		R3	4.7K	C3	0.1 ufd 80-C320C104M5R
Q4	2N7000		R4	330K	C4	680p C0G 80-C315C681J1G
Q5	2N7000		R5	1K	C5	1500p C0G 80-C315C152J1G
Q6	2N4401		R6	1K	C6	680p C0G
Q7	2N4401		R7	470K	C7	100p NPO/C0G 80-C315C101J1G
Q8	2N4401		R8	2.2MEG	C8	0.1 ufd
Q9	2N4401		R9	4.7K	C9	100 ufd 16V ALUM ELECTRO
Q10	2N3819	J-FET	R10	2.2K	C10	0.1 ufd
Q11	2N7000		R11	1MEG	C11	0.1 ufd
Q12	2N4401		R12	2.2K	C12	0.1 ufd
D1	1N4731B	5.1V	R13	1K	C13	0.1 ufd
D2	1N4148		R14	4.7K	C14	100 ufd / 16V
D3	1N4001		R15	10K	C15	0.1 ufd
D4	1N4001		R16	2.2K	C16	100 pfd NPO / C0G
			R17	22K	C17	POLY-VARIABLE 150p QRPKITS
T1	FT37-43	5T	R18	22K	C18	10 ufd / 16V
T2	T50-2		R19	2.2K	C19	0.1 ufd
L1	T50-2	27T	R20	10K	C20	100 pfd NPO/C0G
L2	T37-2	25T	R21	100	C21	0.022 ufd
			R22	1MEG	C22	0.022 ufd FILM 140-PM2A223K
	MOUSER	R's 291-VALUE-RC (10 MIN)			C23	0.022 ufd FILM MOUSER
J1	BNC	USE PANEL MOUNT			C24	0.022 ufd FILM
J2	PWR	CP-102A-ND 2.1mm DIGI-KEY			C25	0.022 ufd FILM
J3/4	STEREO	161-3507-E MOUSER			C26	10 ufd / 16V
					C27	40 p TRIMMER 659-GKG40015
V1	500TRIM	201XR501B-ND DIGI-KEY			C28	47 pfd NPO
V2	50K LIN	317-2091F-50K MOUSER			C29	10 pfd NPO
X1	3.579MHZ	559-FOX036-LF MOUSER			C30	0.1 ufd
					C31	0.1 ufd

Most of the part numbers shown next to the part values are for Mouser. J2 and V1 are sourced from Digi-Key, but be advised they have a $5.00 surcharge for orders of less than $25.00. Toriods are available from www.kitsandparts.com

US 20060184209A1

(19) **United States**

(12) **Patent Application Publication**

(10) **Pub. No.: US 2006/0184209 A1**

(43) **Pub. Date: Aug. 17, 2006**

John et al.

(54) **DEVICE FOR BRAIN STIMULATION USING RF ENERGY HARVESTING**

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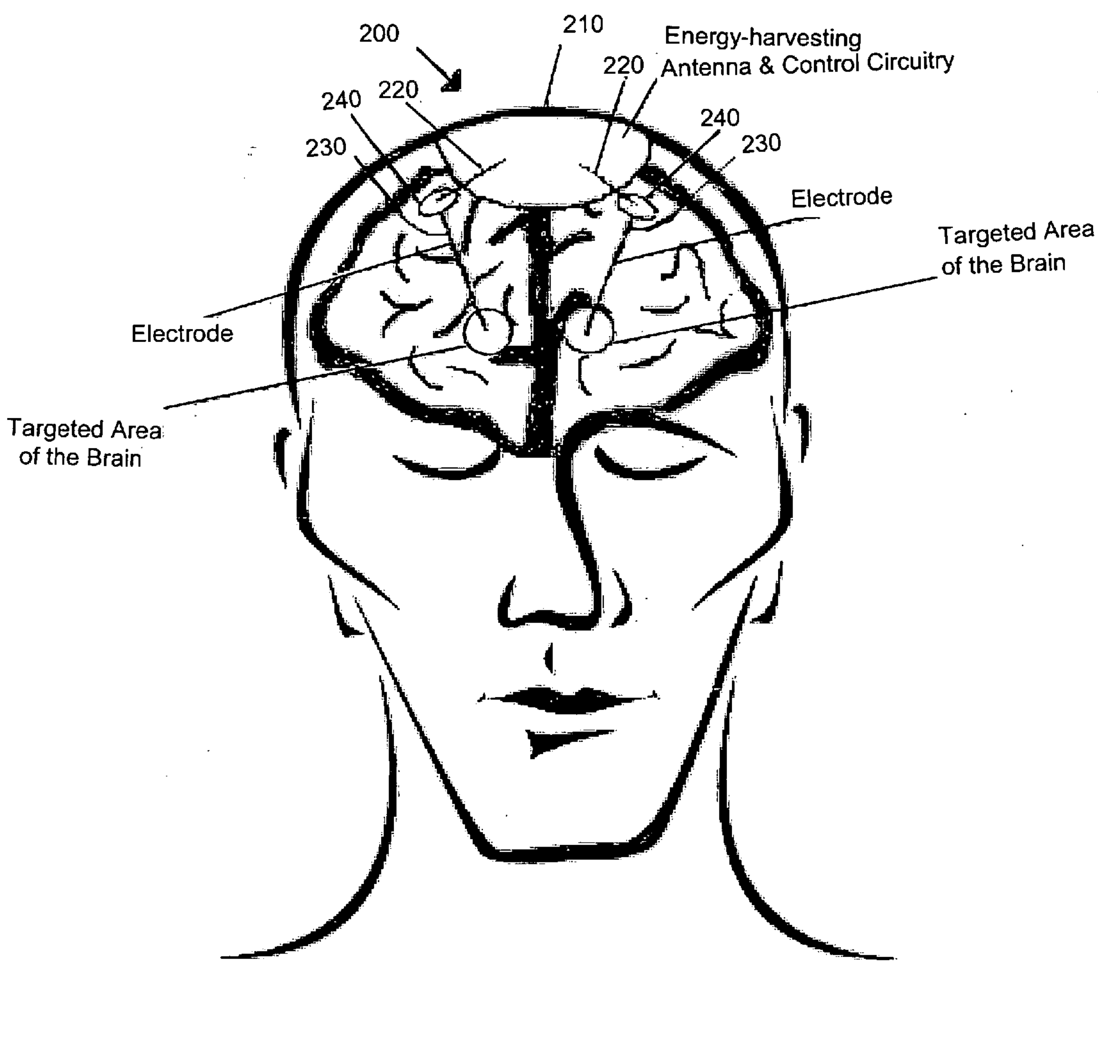
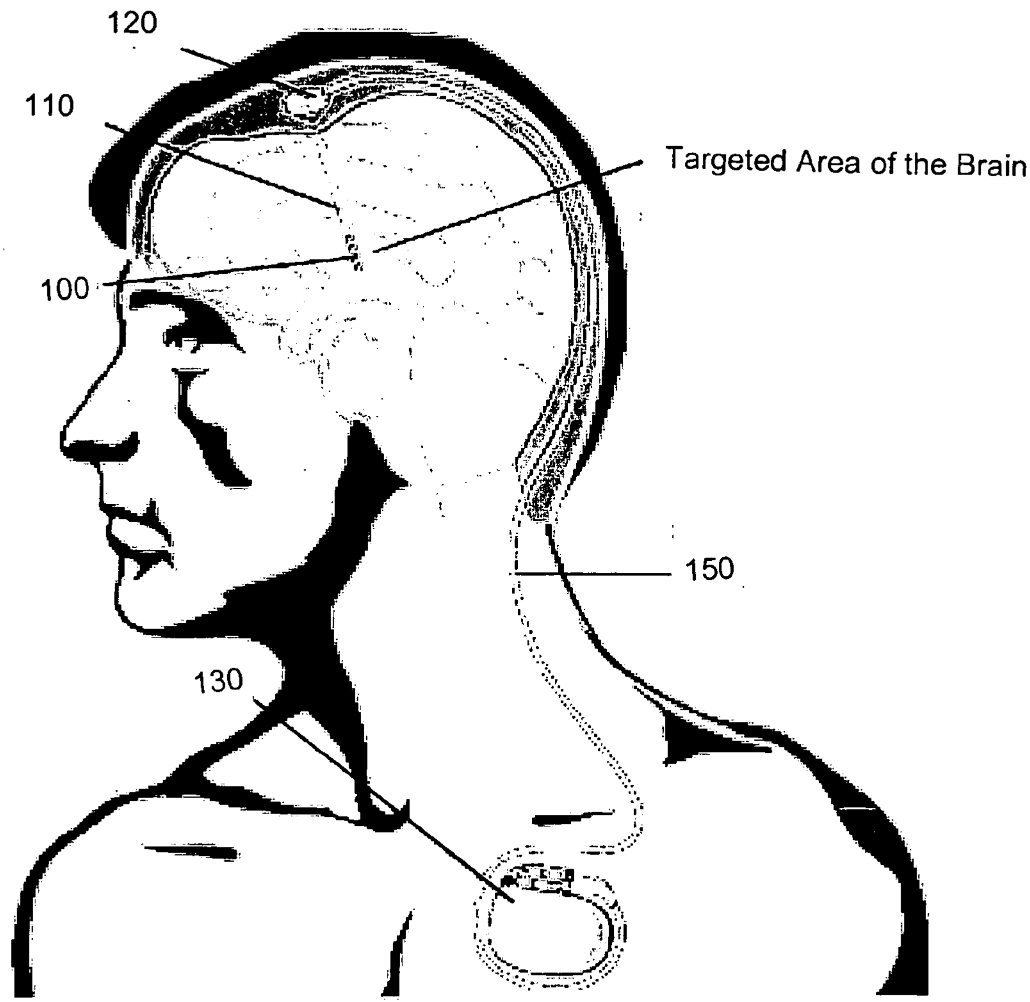
A61N 1/34 (2006.01)

(52) **U.S. Cl.** **607/45**

(57) **ABSTRACT**

A device for brain stimulation using radio frequency harvesting is disclosed. The device includes a circuit implantable under a scalp of a patient, the circuit comprising a radio frequency harvesting power circuit and a stimulation circuit, and a plurality of electrodes coupled to the circuit, the plurality of electrodes providing brain stimulation to targeted areas of the brain. The electrodes may provide stimulation to targeted areas of the brain including deep brain stimulation for the treatment of Parkinson's disease and cortical stimulation for the treatment of stroke victims.





PRIOR ART

FIG. 1

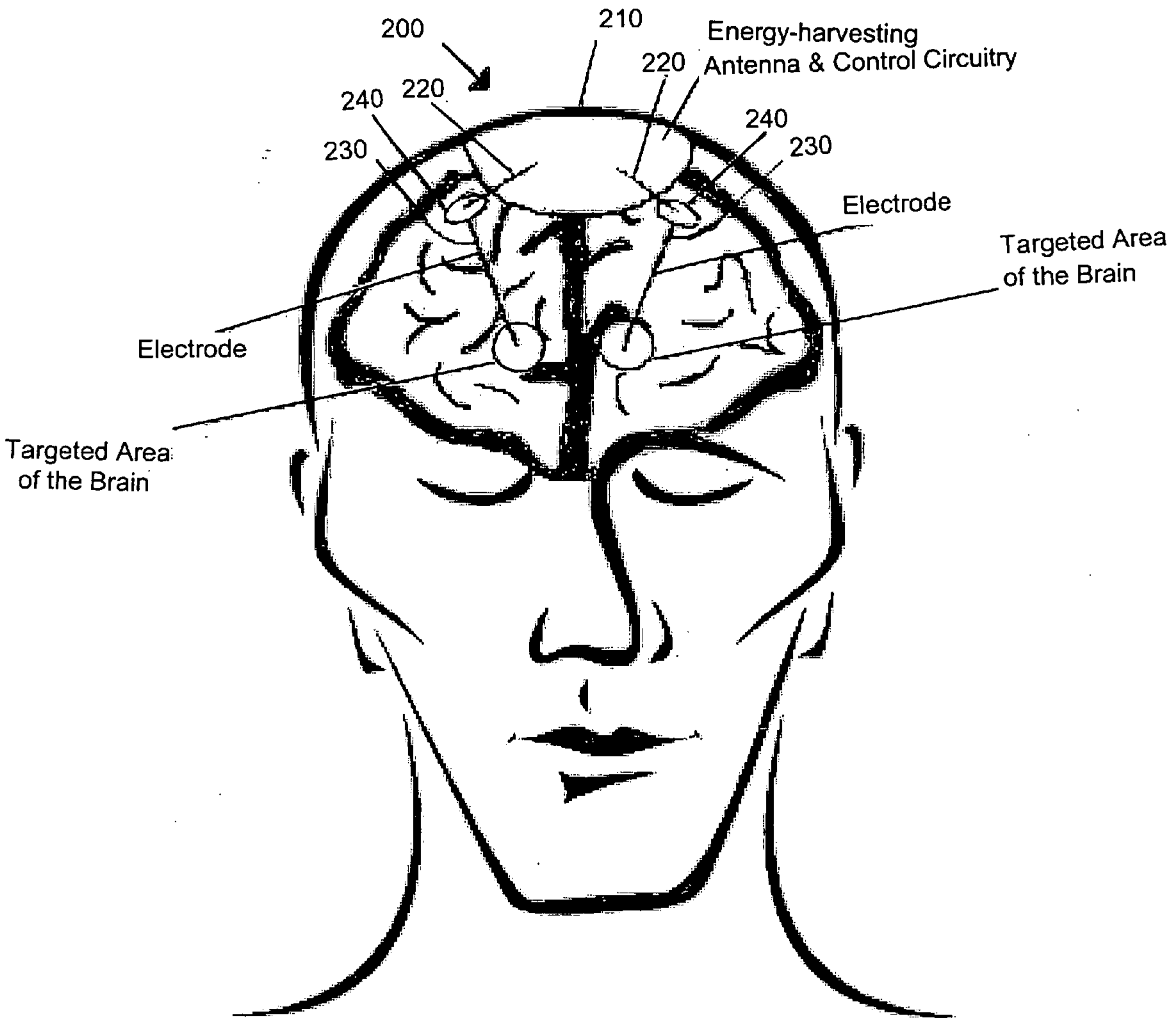

200
210
Energy-harvesting
Antenna & Control Circuitry
220
240
220
240
230
230
Electrode
Targeted Area
of the Brain
Electrode
Targeted Area
of the Brain

FIG. 2A

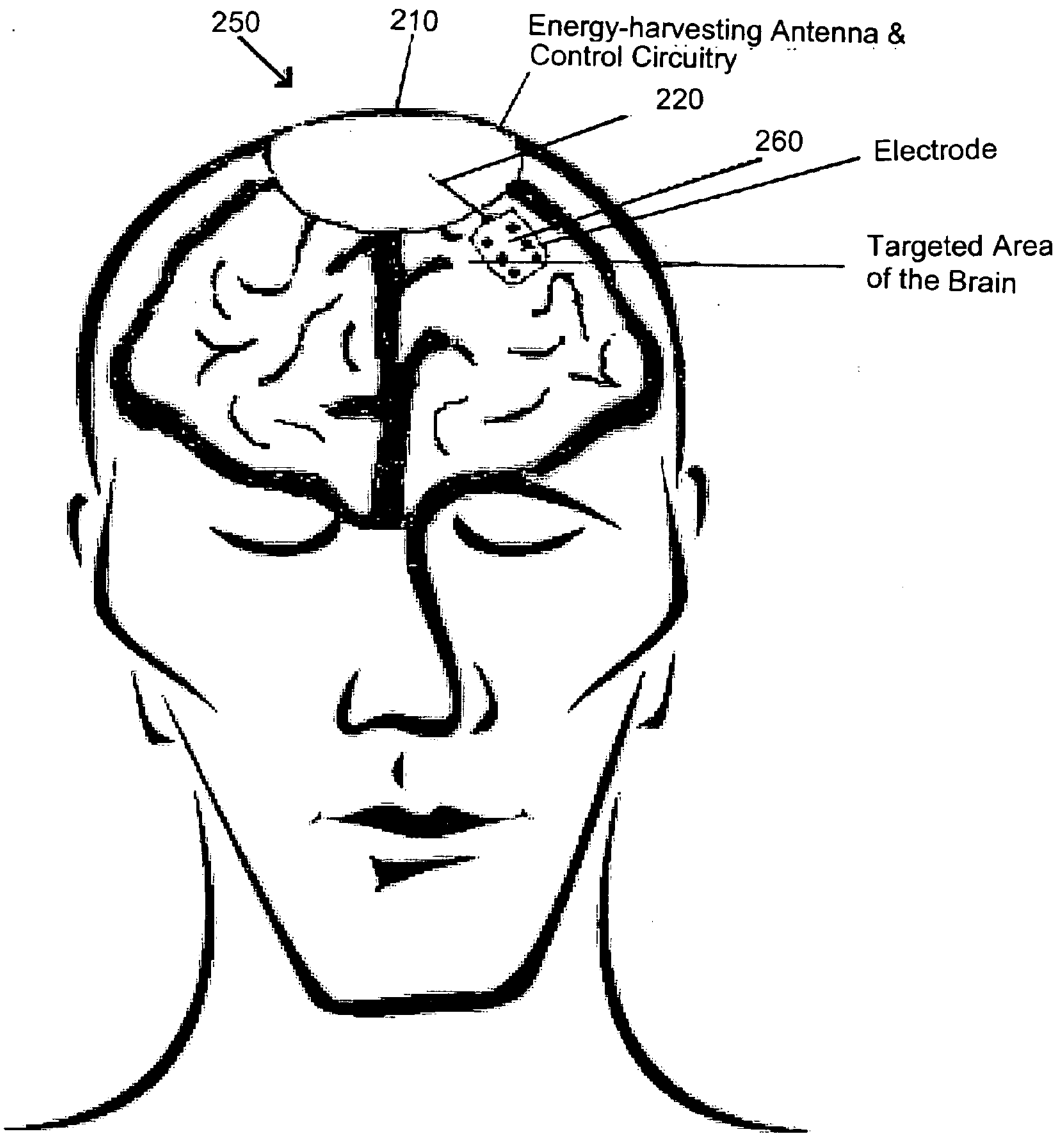

250
210
Energy-harvesting Antenna &
Control Circuitry
220
260
Electrode
Targeted Area
of the Brain

FIG. 2B

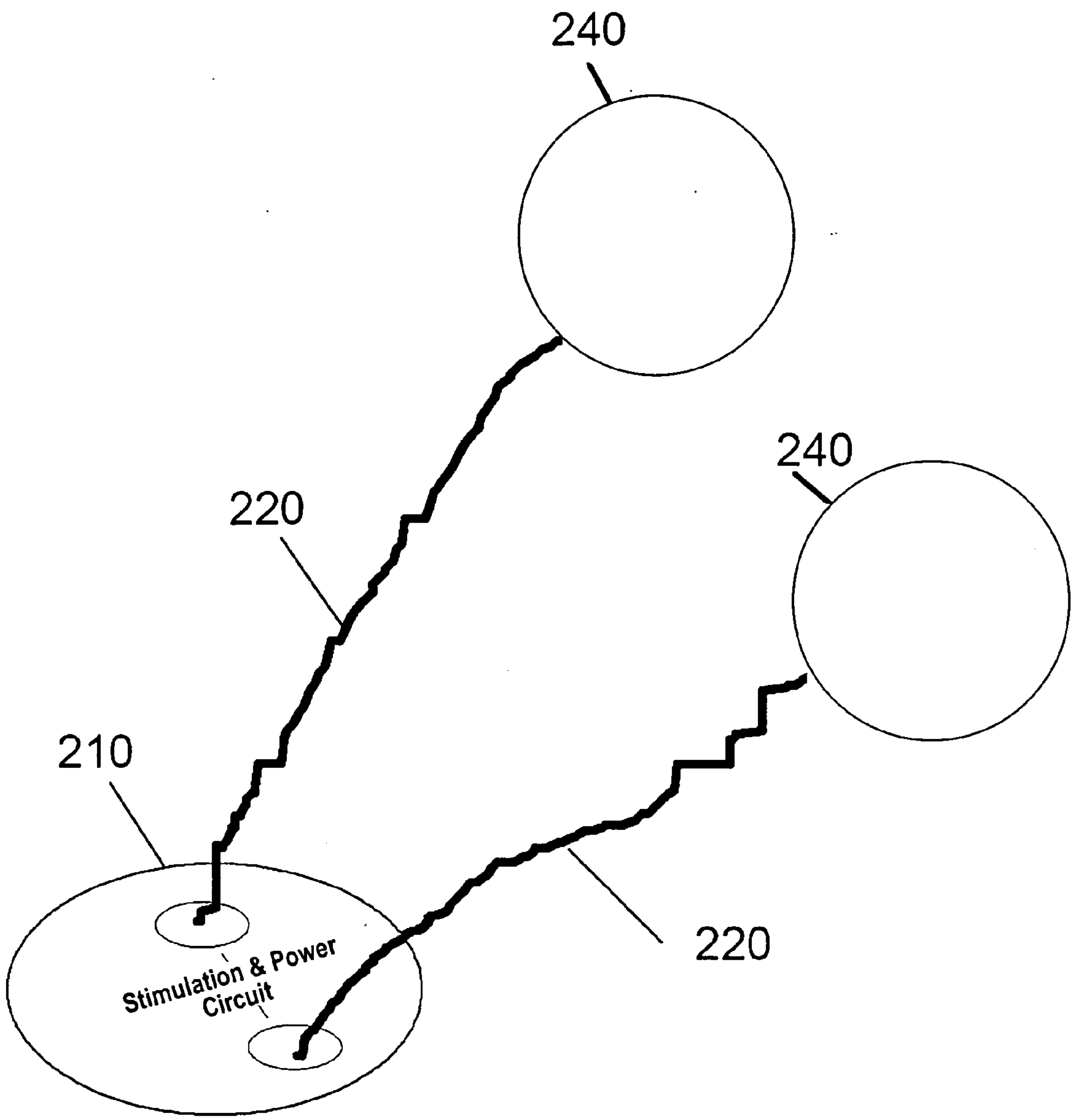


FIG. 2C

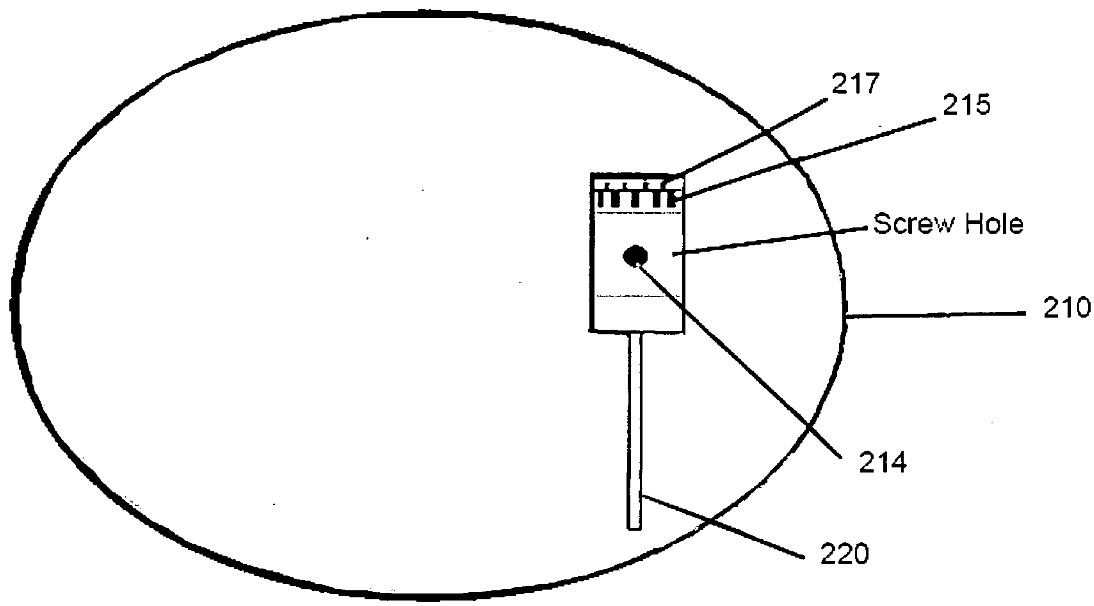


FIG. 2D

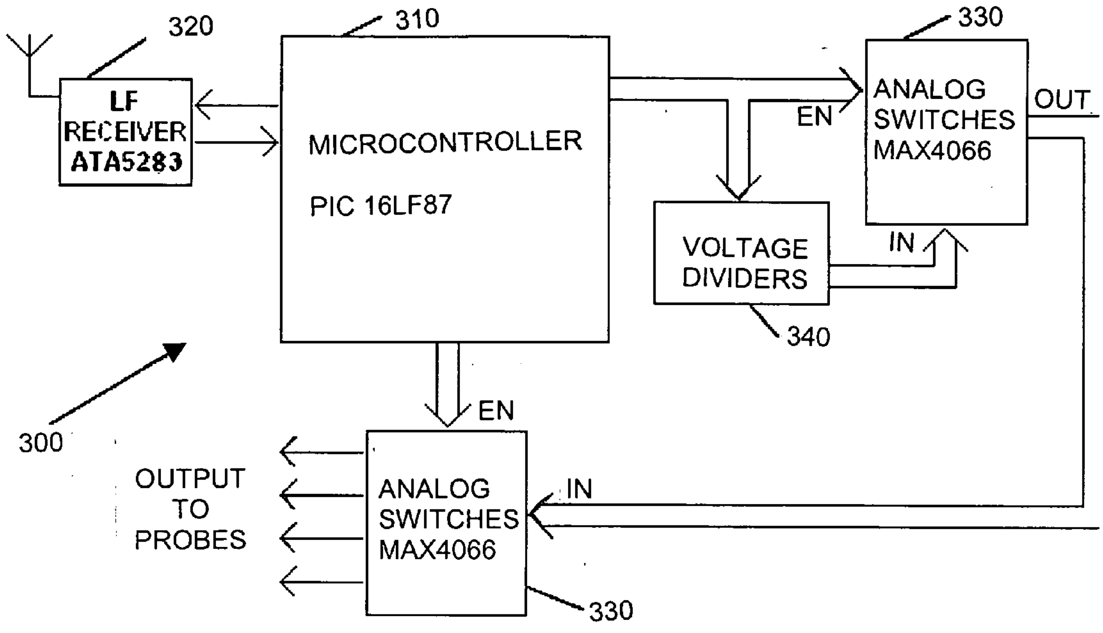

320
LF RECEIVER ATA5283
310
MICROCONTROLLER
PIC 16LF87
330
ANALOG SWITCHES MAX4066
OUT
EN
VOLTAGE DIVIDERS
IN
340
300
EN
OUTPUT TO PROBES
ANALOG SWITCHES MAX4066
IN
330

FIG. 3

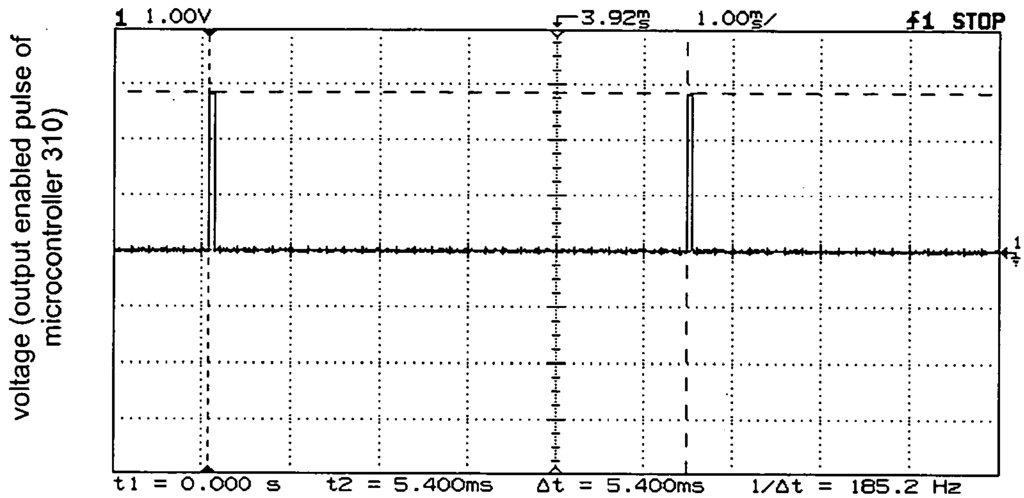

1 1.00V
3.92ms
1.00ms/
f1 STOP
voltage (output enabled pulse of microcontroller 310)
t1 = 0.000 s
t2 = 5.400ms
Δt = 5.400ms
1/Δt = 185.2 Hz

FIG. 4

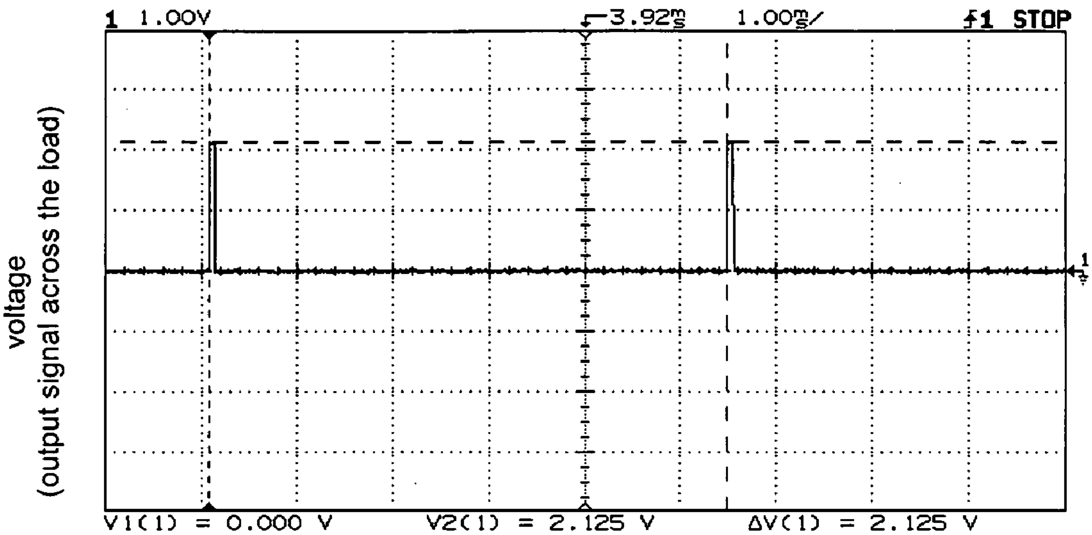

1 1.00V
3.92ms
1.00ms/
f1 STOP
voltage
(output signal across the load)
V1(1) = 0.000 V
V2(1) = 2.125 V
ΔV(1) = 2.125 V

FIG. 5

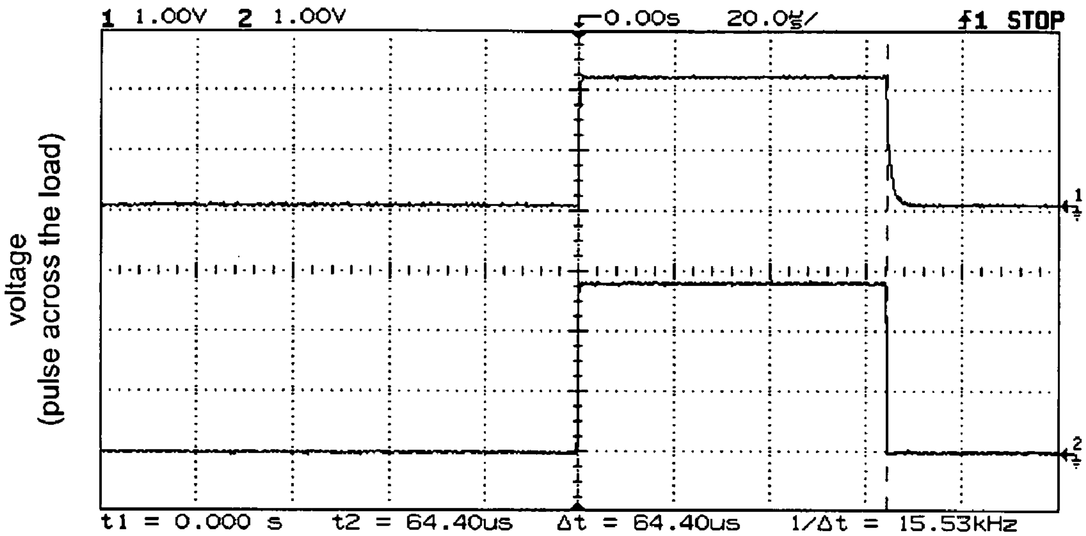

1 1.00V 2 1.00V
0.00s 20.0us/
f1 STOP
voltage
(pulse across the load)
t1 = 0.000 s t2 = 64.40us Δt = 64.40us 1/Δt = 15.53kHz

FIG. 6

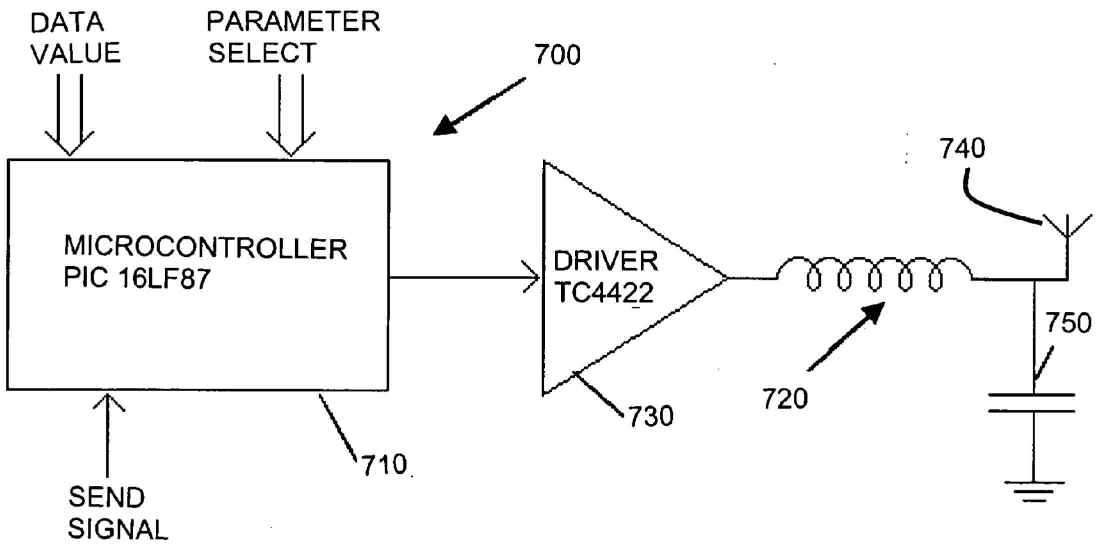

DATA
VALUE
PARAMETER
SELECT
700
740
MICROCONTROLLER
PIC 16LF87
DRIVER
TC4422
750
730
720
710
SEND
SIGNAL

FIG. 7

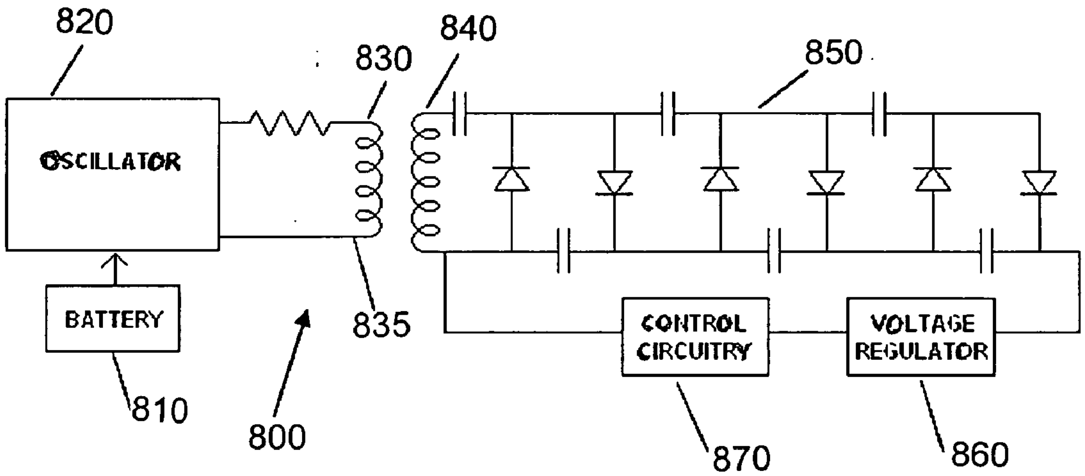

820
OSCILLATOR
BATTERY
810
800
830
835
840
850
CONTROL CIRCUITRY
VOLTAGE REGULATOR
870
860

FIG. 8A

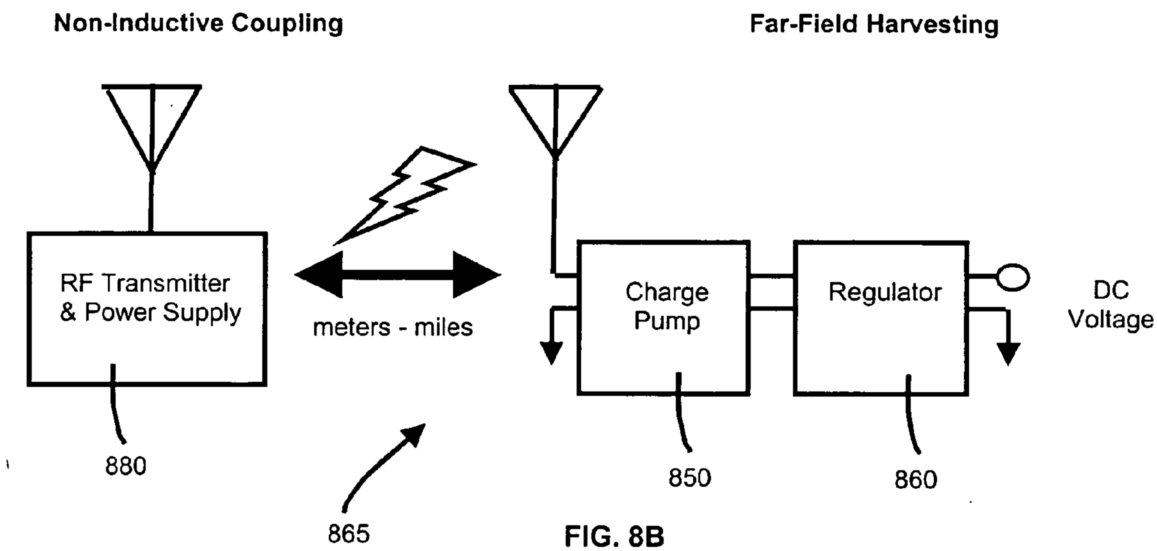

Non-Inductive Coupling
Far-Field Harvesting
RF Transmitter & Power Supply
meters - miles
Charge Pump
Regulator
DC Voltage
880
865
850
860

FIG. 8B

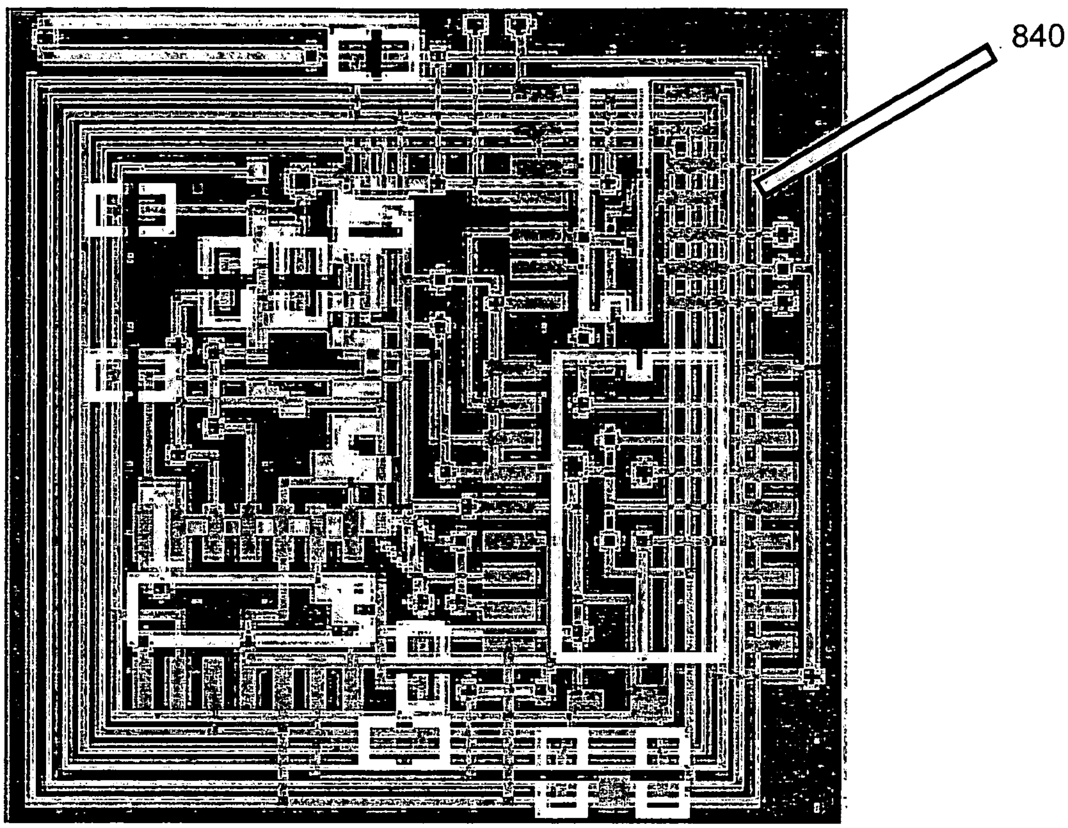


FIG. 9

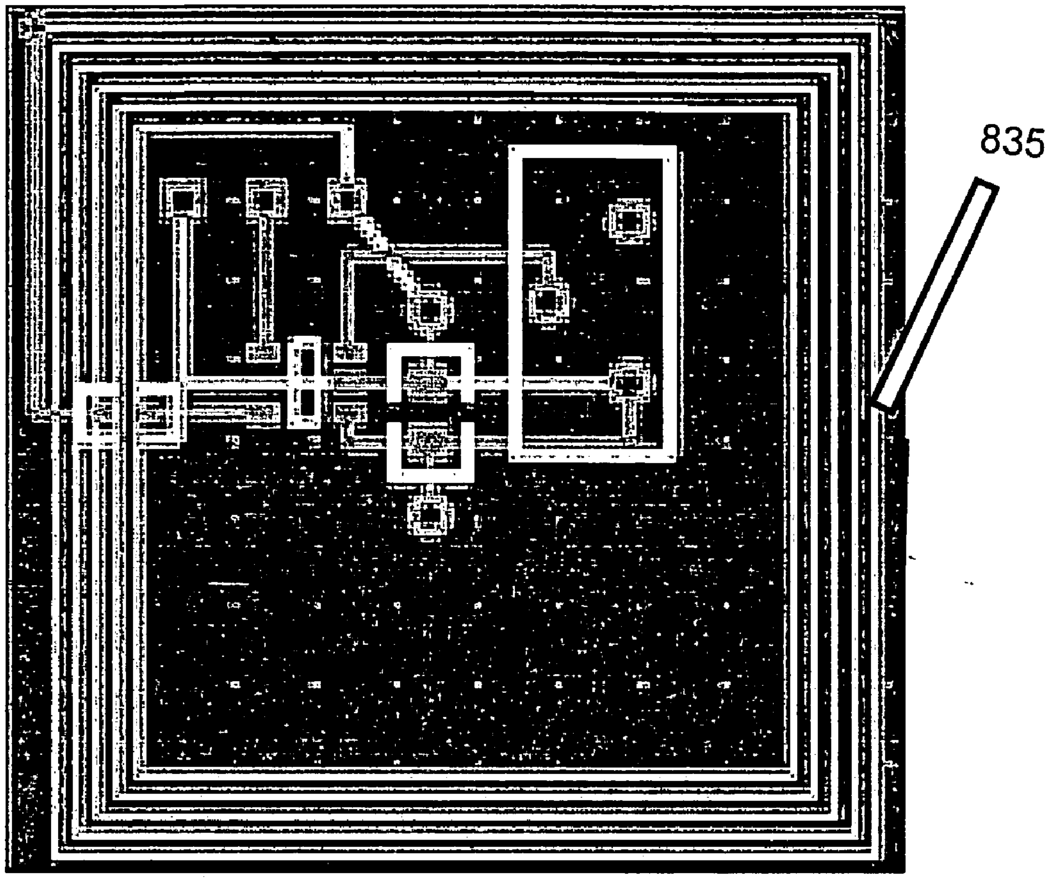


FIG. 10

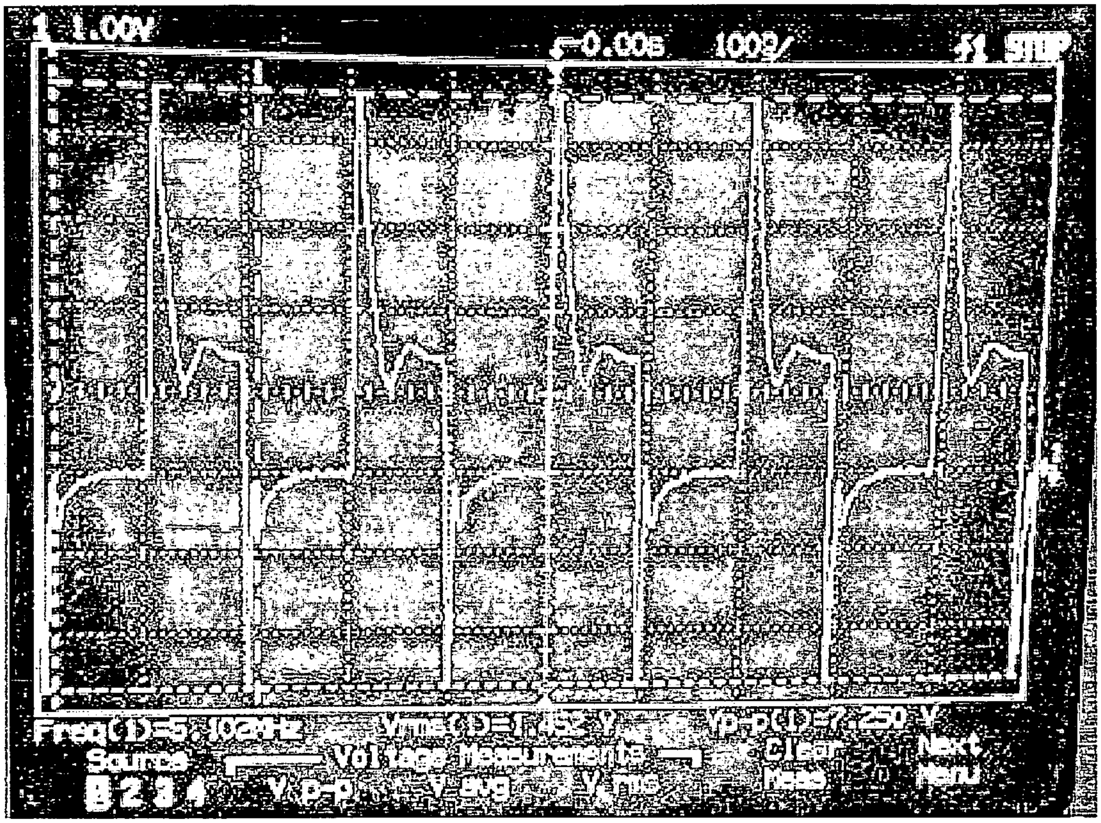

1 1.00V
0.00s
Source
Voltage Measurements
Clear
Meas
Next
Menu
V p-p
V avg
V rms

FIG. 11

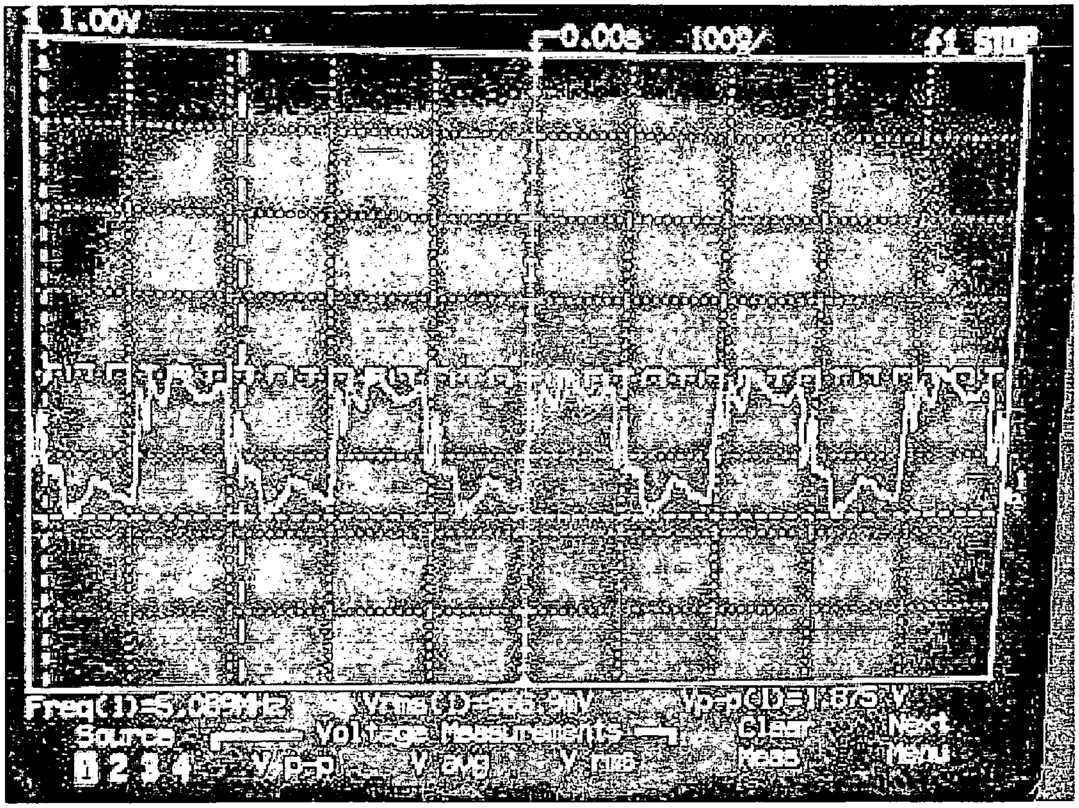

1 1.00V
0.00s 100%
Source
Voltage Measurements
Clear
Meas
Next
Menu
1 2 3 4
V p-p
V avg
V rms

FIG. 12

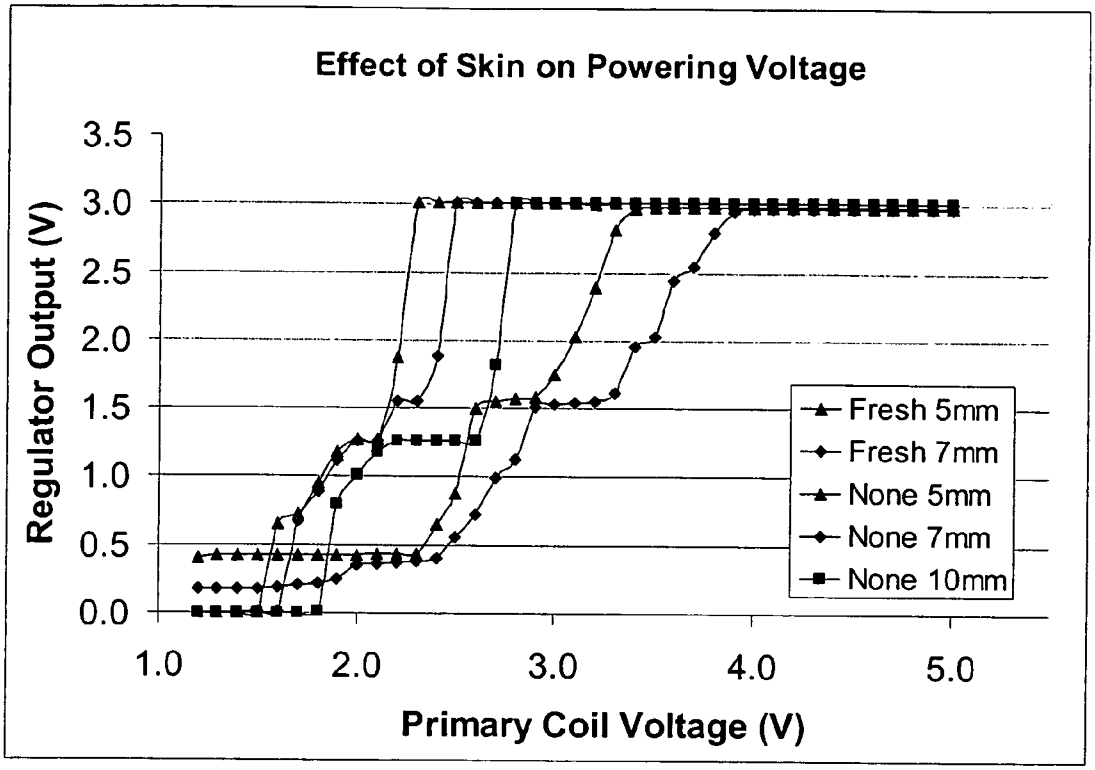

Effect of Skin on Powering Voltage
3.5
3.0
2.5
2.0
1.5
1.0
0.5
0.0
Regulator Output (V)
1.0
2.0
3.0
4.0
5.0
Primary Coil Voltage (V)
Fresh 5mm
Fresh 7mm
None 5mm
None 7mm
None 10mm

FIG. 13

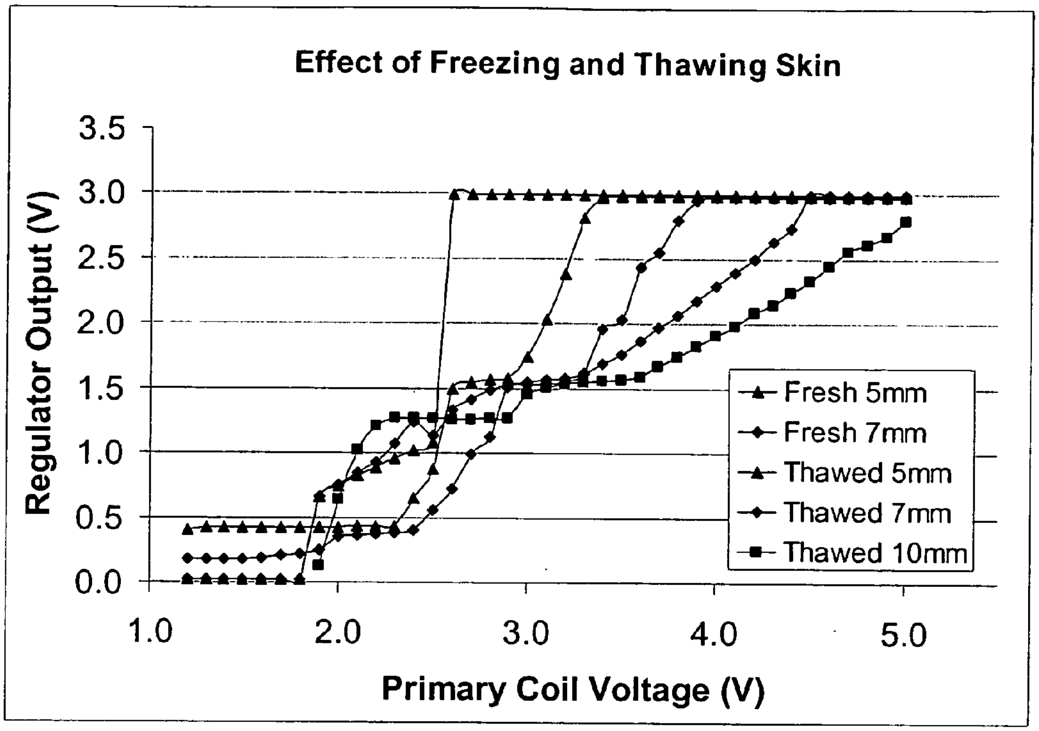

Effect of Freezing and Thawing Skin
Regulator Output (V)
3.5
3.0
2.5
2.0
1.5
1.0
0.5
0.0
1.0
2.0
3.0
4.0
5.0
Primary Coil Voltage (V)
Fresh 5mm
Fresh 7mm
Thawed 5mm
Thawed 7mm
Thawed 10mm

FIG. 14

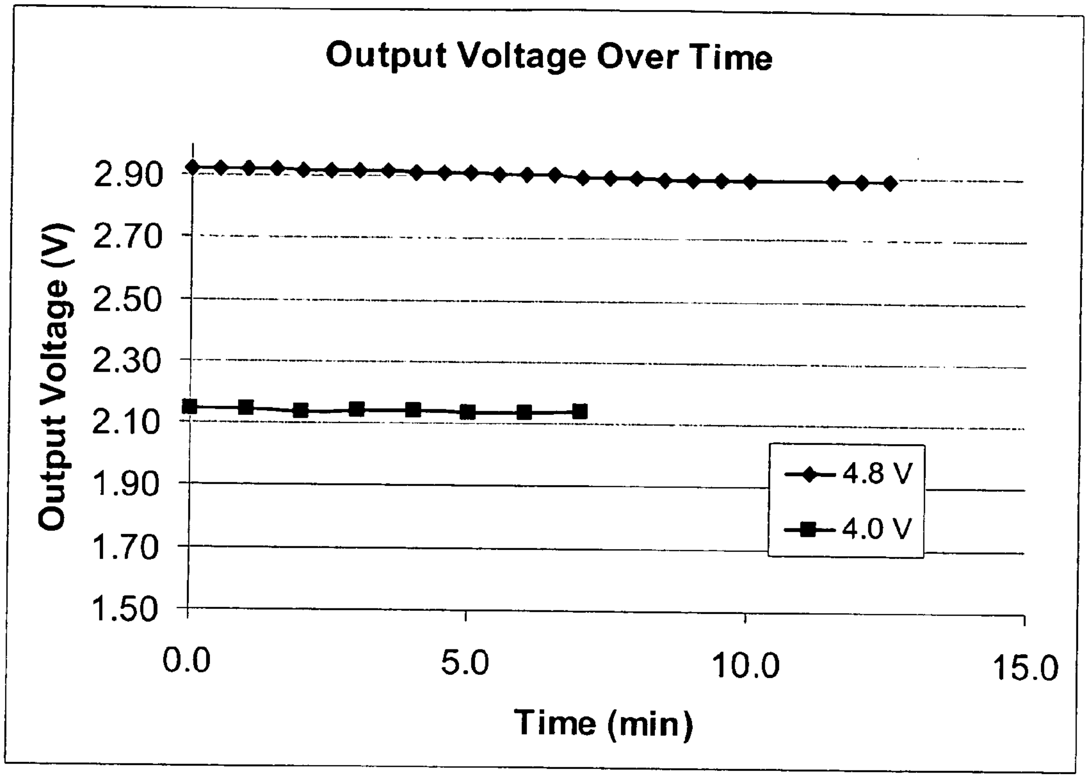

Output Voltage Over Time
Output Voltage (V)
2.90
2.70
2.50
2.30
2.10
1.90
1.70
1.50
0.0
5.0
10.0
15.0
Time (min)
4.8 V
4.0 V

FIG. 15

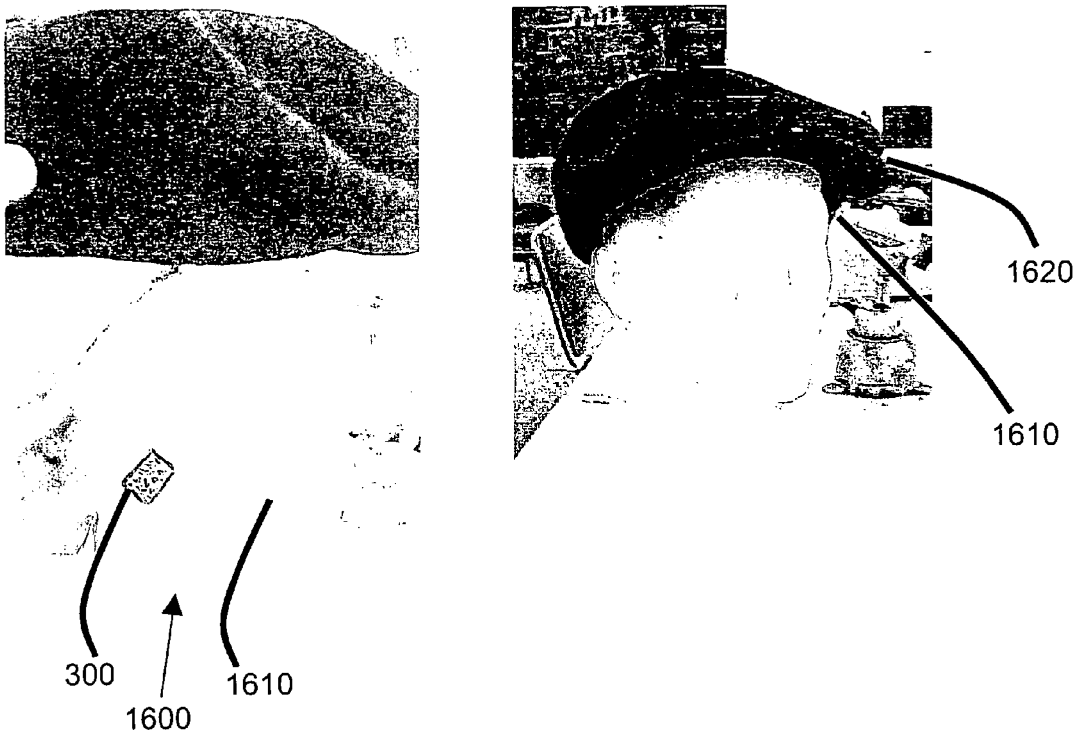


FIG. 16

DEVICE FOR BRAIN STIMULATION USING RF ENERGY HARVESTING

CROSS REFERENCE TO RELATED APPLICATIONS

[0001] The present application claims priority under 35 U.S.C. 119(e) from provisional patent application Ser. No. 60/606,853, entitled "Device For Deep Brain Stimulation (DBS) Using RF Energy Harvesting", filed on Sep. 2, 2004, the disclosure of which is herein incorporated by reference in its entirety.

FIELD OF THE INVENTION

[0002] The present invention relates generally to systems and apparatus for providing brain stimulation and more particularly to a device for harvesting radio frequency (RF) energy that can be implanted under a human scalp to produce stimulation in different regions of the brain, including deep brain stimulation (DBS).

BACKGROUND OF THE INVENTION

[0003] DBS is a surgical technique first used in humans over 25 years ago. DBS has been used in a wide variety of brain targets, including the thalamus, globus pallidus and the subthalamic nucleus. Diseases that have been effectively treated with DBS include movement disorders including essential tremor [Lyons K E, Pahwa R. Deep Brain Stimulation and Essential Tremor, J Clin Neurophysiol. 2004 January-February;21(1):2-5], Parkinson's disease [Byrd D L, Marks W J Jr, Starr P A. Deep brain stimulation for advanced Parkinson's disease. AORN J. 2000 September;72(3):387-90, 393-408] and dystonia [Vidailhet M. et al., Bilateral deep-brain stimulation of the globus pallidus in primary generalized dystonia. N Engl J Med. 2005 Feb. 3;352(5):459-67]. Other indications for DBS are being explored, including chronic pain, cluster headache, persistent vegatative state, epilepsy, Alzheimer's, and psychiatric disorders including obsessive-compulsive disorder and intractable depression.

[0004] Parkinson's disease (PD) is an idiopathic neurodegenerative disorder that is characterized by the presence of tremor, rigidity, akinesia or bradykinesia (slowness of movement) and postural instability. It is believed to be caused by the loss of a specific, localized population of neurons in a region of the brain called the substantia nigra. These cells normally produce dopamine, a neurotransmitter that allows brain cells to communicate with each other. These dopaminergic cells in the substantia nigra are part of an elaborate motor circuit in the brain that runs through a series of discrete brain nuclei known as the basal ganglia that control movement. It is believed that the symptoms of PD are caused by an imbalance of motor information flow through the basal ganglia.

[0005] Conventionally, a medication known as levodopa has been the mainstay of treatment for patients with Parkinson's disease. However, long-term therapy with levodopa has several well-known complications that limit the medications effectiveness and tolerability. The first of these is the development of involuntary movements known as dyskinesias. These movements can be violent at times and as or more disabling than the Parkinson's symptoms themselves. The other frequent complication is the development of "on-off" fluctuations, where patients cycle between periods of good function (the "on" period) and periods of poor function (the "off" period). These fluctuations can become very frequent, up to 7 or more cycles per day, and can cause patients to become suddenly and unpredictably "off" to the point where they cannot move.

[0006] Lesioning procedures such as pallidotomy were known to improve the motor symptoms of Parkinson's disease, presumably by disruption of the abnormal neuronal activity in the motor circuitry of the basal ganglia. The discovery that MPTP (1-methyl-4-phenyl-1,2,3,6-tetrahydropyridine) produced a Parkinsonian-like state in non-human primates allowed electrophysiologic study of this phenomenon by numerous investigators. The discovery that high frequency stimulation could mimic the effect of lesioning led to the use of DBS for PD in humans in the early 1990's. DBS was found to improve all of the cardinal symptoms of Parkinson's disease while allowing the patient to decrease or sometimes even eliminate the amount of levodopa medication, therefore decreasing both dyskinesia and "on-off" fluctuations.

[0007] DBS is currently the surgical treatment of choice for medically refractory Parkinson's disease. Two brain targets have been found to provide clinical benefit when chronically stimulated; the subthalamic nucleus (STN) and the internal segment of the globus pallidus (GPi). In a recent prospective, double-blinded cross-over study involving 96 patients with STN DBS and 38 patients with GPi DBS, the STN group reported an improvement in the percentage of time spent during the day with good mobility and without dyskinesia from 27% to 74%. The GPi group also reported a significant improvement, from 28% to 64%.

[0008] Although the mechanism of action is not fully understood it is thought to act by either depolarization blockade, synaptic inhibition, synaptic depression, or stimulation-induced modulation of pathologic network activity [McIntyre C C, Savasta M, Walter B L, Vitek J L. How does deep brain stimulation work? Present understanding and future questions. J Clin Neurophysiol. 2004 January-February;21(1):40-50]. It is believed that DBS acts somehow to suppress the neuronal activity by the stimulation of the region of the brain immediately adjacent to the electrode. This hypothesis seems to be supported by the fact that lesioning a specific structure in the brain has the same clinical effect as stimulating that same structure at high (greater than 100-150 Hz) frequency. In fact, DBS has largely replaced the older lesioning procedures (such as pallidotomy and thalamotomy) that used to be the mainstay of surgical treatment for movement disorders such as Parkinson's disease. The high frequency stimulation may act to hyperpolarize immediately adjacent neurons such that they become incapable of producing normal action potentials. An alternative hypothesis is that DBS may be altering more distant structures or even fibers from far removed nerve cells that are passing through or near the area of stimulation. Whatever the mechanism of action, DBS has a distinct advantage over the older lesioning techniques because it is an adjustable therapy and does not involve destruction of the patient's brain tissue.

[0009] Prior art DBS devices have several limitations that can lead to adverse effects including infection, cutaneous erosion, and lead breaking or disconnection [Temel Y,

Ackermans L, Celik H, Spincemaille G H, Van Der Linden C, Walenkamp G H, Van De Kar T, Visser-Vandewalle V. Management of hardware infections following deep brain stimulation. Acta Neurochir (Wien) 2004;146(4):355-61; Putzke J D, Wharen R E, Jr., Wszolek Z K, Turk M F, Strongosky A J, Uitti R J. Thalamic deep brain stimulation for tremor-predominant Parkinson's disease. Parkinsonism Relat Disord 2003;10(2):81-8.; Umemura A, Jaggi J L, Hurtig H I, Siderowf A D, Colcher A, Stern M B, Baltuch G H. Deep brain stimulation for movement disorders: morbidity and mortality in 109 patients. J Neurosurg 2003;98(4):779-84; Hariz M I. Complications of deep brain stimulation surgery. Mov Disord 2002;17(Suppl 3):S162-**6**]. One study found that 27% of 66 patients with implanted DBS devices had hardware problems [Kondziolka D, Whiting D, Germanwala A, Oh M. Hardware-related complications after placement of thalamic deep brain stimulator systems. Stereotact Funct Neurosurg 2002;79(3-4):228-33. This relatively high incidence of hardware problems is similar to the results of a study where 20 (25.3%) of 79 patients who received 124 permanent DBS electrode implants had 26 hardware-related complications [Oh M Y, Abosch A, Kim S H, Lang A E, Lozano A M. Long-term hardware-related complications of deep brain stimulation. Neurosurgery 2002;50(6):1268-74; discussion 1274-**6**]. In addition, intracranial electrode implantation can induce a hematoma or contusion. Nonetheless, most authors agree that the benefit to risk ratio of DBS is favorable.

[0010] A prior art DBS device is shown in **FIG. 1** and includes an electrode **100** disposed in a targeted area of the brain. The electrode is coupled to a lead **110** held in place at the top of the skull by a securement device **120**. The lead **110** is coupled to a neurostimulator **130** powered by a battery-powered pulse generator **140** by means of a lead **150**. The lead **150**, which averages about 15 inches in length, is implanted under the scalp and traverses the length of the patient's neck to the chest where the neurostimulator **130** and battery **140** are implanted.

[0011] The pulse generator **140** is typically placed underneath the skin just below the collar bone and is capable of stimulating at one or any combination of the four contacts present on the end of the electrode **110** in the brain. The parameters of the stimulating current (voltage, frequency, pulse width) can also be selected by the treating physician or health care worker. The pulse generator **140** is programmed through the skin via a telemetry device that allows the practitioner to select the desired stimulation parameters and also perform diagnostic tests on the device.

[0012] Implantation of the conventional DBS device is costly as for implantation of a single electrode in the brain for treatment of one side of the body the procedure requires three incisions; one on the top of the head, one behind the ear and the third just below the collarbone where the leads are connected. The implantation of the electrode **110** and the implantable pulse generator **140** is sometimes performed on different days. The incisions can be prone to infection in the immediate postoperative period. In some elderly patients with thin skin, the pulse generator **140** or wire can erode through the skin and become exposed to potential contamination. Infection or erosion often results in the need to remove the entire device, as antibiotic treatment alone in this setting rarely will clear the infection adequately. The lead **150** restricts the patient's mobility in the neck region and may break. Furthermore, the battery **140** must be replaced every three to five years. Additional drawbacks of the DBS device include the risk of erosion of the leads or hardware, infection, and magnetic sensitivity.

[0013] A prior art deep brain stimulation system is disclosed in U.S. Pat. No. 6,920,359 entitled "Deep Brian Stimulation System for the Treatment of Parkinson's Disease or Other Disorders". The DBS system includes a small, implantable pulse generator implanted directly in the cranium of the patient, thereby eliminating the long lead wires conventionally used. The disclosed system does not provide for the harvesting of energy to power the pulse generator.

[0014] As noted in Table 1, there are several current and potential indications for deep brain stimulation.

[0015] Known systems for providing electrical stimulus to the motor cortex of the brain, such as the Northstar Stroke Recovery Treatment System available from Northstar Neuroscience, Inc., also include an implantable pulse generator implanted in the pectoral area of a patient. A cortical stimulation lead includes an electrode connected to the implantable pulse generator which is used to deliver stimulation to the cortex. The electrode is placed on top of the dura and coupled to the implantable pulse generator by means of a lead which traverses the length of the patient's neck to the patient's pectoral area.

[0016] Motor cortex stimulation (MCS) is a process involving the application of stimulation signals to the motor cortex in the brain of a patient during physical rehabilitation of the disabled region of the body. The MCS system includes a pulse generator connected to a strip electrode that is surgically implanted over a portion of only the motor cortex (precentral gyrus). Because MCS involves the application of stimulation signals to surface regions of the brain rather than deep neural structures, electrode implantation procedures for MCS are significantly less invasive and time consuming than those for DBS. The current evaluation of MCS is for stroke. Stroke-related disabilities affect more than 200,000 people in the U.S. each year. Good results have been reported in MCS treatment of stroke victims. With a MCS device, a stamp-sized electrode is placed on the surface of the brain. This is attached to a wire that goes through the neck to an implantable pulse generator in the pectoral area.

[0017] Neurostimulation and responsive neurostimulation (RNS) are also being tested for the treatment of medically refractory epilepsy. In treating epilepsy, the RNS system can be designed to detect abnormal electrical activity in the brain and respond by delivering electrical stimulation to normalize brain activity before the patient experiences seizure symptoms. For either neurostimulation or RNS for treatment of epilepsy the electrode or electrodes of the device deliver a short train of electrical pulses to the brain near the patient's seizure focus.

[0018] In order to obviate the need for long leads and batteries, attempts have been made in the prior art to transmit energy through space from a base station to a remote station. One such system is disclosed in U.S. Pat. No. 6,289,237 entitled "Apparatus for Energizing a Remote Station and Related Method". The base station transmits energy which may be RF power, light, acoustic, magnetic or other suitable forms of space transmitted or "radiant" energy to the remote station. Within the remote station, the received

energy is converted into DC power which serves to operate the remote station. The source of power for the remote station is the base station and, therefore, there is no need for the remote station to carry an electrical storage device such as a battery. It is suggested that this facilitates the remote station being encapsulated within a suitable protective material, such as a resinous plastic. Homopolymers, elastomers and silicon dioxide are also suggested as suitable materials for such purposes. Further, it is suggested that this facilitates miniaturization of the remote station and placing the remote station in functionally desirable locations which need not be readily accessible. The remote station, for example, could be implanted in a patient.

[0019] The use of a wireless communication link between a base station and transponders in a radio frequency identification system employing modulated back-scattered waves is also known. See Rao, An Overview of Bulk Scattered Radio Frequency Identification System (RFID) IEEE (1999). It has also been suggested to employ a silicon chip in a transponder having a change pump on voltage doubler current. Hornby, RFID Solutions for the Express Parcel and Airline Baggage Industry, Texas Instruments, Limited (Oct. 7, 1999).

[0020] For use in miniaturized electronic chip systems, an electronic article containing a microchip having at least one antenna structured to communicate with an antenna remotely disposed with respect to the microchip is disclosed in U.S. Pat. No. 6,615,074 entitled “Apparatus for Energizing a Remote Station and Related Method”. Power enhancement is achieved using a voltage doubler. The antenna of the disclosed apparatus is comparable in volume to a Smart Dust device. Smart Dust is a combination MEMS/Electronic device on the order of 1 mm×1 mm×1 mm.

[0021] What is needed therefore is a brain stimulation device that overcomes the disadvantages of the prior art brain stimulation devices. What is needed is a brain stimulation device that requires a single implantation site and surgery. What is also needed is a brain stimulation device that uses RF energy as a power source. What is further needed is a brain stimulation device that converts RF energy and stores the converted RF energy. What is also needed is a brain stimulation device that is flexible and implantable under the scalp. What is needed is a brain stimulation device that does not require leads or a pulse generator to be placed outside of the head area that are subject to disconnection or breakage. What is also needed is a brain stimulation device for electrical stimulation in the brain that is smaller and more self-contained and that does not require a pulse generator to be implanted elsewhere in the body. What is further needed is a device that is less susceptible to hardware problems or complications. What is needed is a device that has less potential for erosion through the skin. What is also needed is a device that is has a power source that does not need to be replaced.

SUMMARY OF INVENTION

[0022] The device for brain stimulation using RF energy harvesting of the present invention overcomes the disadvantages of the prior art, fulfills the needs in the prior art, and accomplishes its various purposes by providing a brain stimulation device that harvests radio frequency energy and is implantable under the scalp. The brain stimulation device of the invention may include an electrode that penetrates into the brain to provide neurostimulation to the brain. The brain stimulation device may also include an electrode that is used to provide stimulation to the brain cortex.

[0023] In accordance with one aspect of the invention, a device for brain stimulation using radio frequency harvesting includes a circuit implantable under a scalp of a patient, the circuit comprising a radio frequency harvesting power circuit and a stimulation circuit, and a plurality of electrodes coupled to the circuit, the plurality of electrodes providing brain stimulation to targeted areas of the brain. An advantage of this system is that it may use “trickle charging” wherein the device is charged by the harvesting power circuit. Moreover, anther advantage of this invention is the power transmitter which sends power to the device can be used both to send power and to send information.

[0024] There has been outlined, rather broadly, the more important features of the invention in order that the detailed description thereof that follows may be better understood, and in order that the present contribution to the art may be better appreciated. There are, of course, additional features of the invention that will be described below and which will form the subject matter of the claims appended herein.

[0025] In this respect, before explaining at least one embodiment of the invention in detail, it is to be understood that the invention is not limited in its application to the details of design and to the arrangement of components set forth in the following description or illustrated in the drawings. The invention is capable of other embodiments and of being practiced and carried out in various ways. Also, it is to be understood that the phraseology and terminology employed herein, as well as the abstract, are for the purpose of description and should not be regarded as limiting.

[0026] As such, those skilled in the art will appreciate that the conception upon which this disclosure is based may readily be utilized as a basis for the designing of other methods and systems for carrying out the several purposes of the present invention. It is important, therefore, that the claims be regarded as including such equivalent methods and systems insofar as they do not depart from the spirit and scope of the present invention.

BRIEF DESCRIPTION OF THE DRAWINGS

[0027] The accompanying drawings, which are incorporated in and form a part of the specification, illustrate the embodiments of the present invention and together with the description, serve to explain the principles of the invention. In the drawings:

[0028] **FIG. 1** is a schematic representation of a prior art DBS device;

[0029] **FIG. 2A** is a schematic representation of a device for deep brain stimulation using RF energy harvesting in accordance with the invention;

[0030] **FIG. 2B** is a schematic representation of a device for cortical stimulation using RF energy harvesting in accordance with the invention;

[0031] **FIG. 2C** is a schematic representation of the device of **FIG. 2A** illustrating lead securement devices;

[0032] **FIG. 2D** is a schematic representation of the device of **FIG. 2A** illustrating an attachment means for connecting a lead wire to a circuit of the device;

[0033] **FIG. 3** is a schematic representation of a stimulation circuit in accordance with the invention;

[0034] **FIG. 4** is a graph showing an output enable pulse from a microcontroller of the stimulation circuit shown in **FIG. 3** in accordance with the invention;

[0035] **FIG. 5** is a graph showing an output signal from the microcontroller of the stimulation circuit shown in **FIG. 3** applied across a resistive load in accordance with the invention.

[0036] **FIG. 6** is a graph showing pulses across the resistive load;

[0037] **FIG. 7** is a schematic representation of an external programming circuit in accordance with the invention;

[0038] **FIG. 8A** is a schematic representation of an external power circuit inductively coupled to a power circuit in accordance with the invention;

[0039] **FIG. 8B** is a schematic representation of an alternative embodiment of the external power circuit non-inductively coupled to the power circuit in accordance with the invention;

[0040] **FIG. 9** is an illustration of a PCB layout of the stimulating circuit in accordance with the invention;

[0041] **FIG. 10** is an illustration of the external power circuit in accordance with the invention/

[0042] **FIG. 11** is an oscilloscope screen showing the output voltage from an oscillator of the external power circuit in accordance with the invention;

[0043] **FIG. 12** is an oscilloscope screen showing a voltage across a primary coil series resistance of the external power circuit in accordance with the invention;

[0044] **FIG. 13** is a graph showing the effect of skin disposed between the primary coil and a secondary coil of the stimulating circuit in accordance with the invention;

[0045] **FIG. 14** is a graph showing the effect of freezing the thawing the skin in accordance with the invention;

[0046] **FIG. 15** is a graph of the output voltage over time in accordance with the invention; and

[0047] **FIG. 16** is a pictoral representation of a model having the stimulation circuit implanted in a scalp and the external powering circuit disposed in a hat in accordance with the invention.

DETAILED DESCRIPTION OF THE INVENTION

[0048] A device for deep brain stimulation using RF energy harvesting **200** of he invention is shown implanted under a human scalp in **FIG. 2A**. A flexible, implantable disc-shaped portion **210** having a diameter of about 6 cm and a thickness of between 3 and 4 mm may be formed of a biocompatible material and include circuitry as further described herein. Lead wires **220** may lead from the circuitry and be coupled to electrodes **230** disposed in targeted areas of the brain. Electrodes **230** may include conventional electrodes used for DBS. Neurostimulation lead securement devices **240** including burr hole caps may serve to secure the lead wires **220** to the electrodes. The circuitry may be operable to harvest and store RF energy, control the operation of the device **200** and provide neurostimulation pulses and signals to the targeted areas of the brain.

[0049] A device for cortical brain stimulation using RF energy harvesting **250** of the invention is shown in **FIG. 2B**. The flexible, implantable disc-shaped portion **210** is shown implanted under the scalp. Lead wires **270** may lead from the circuitry of the disc-shaped portion **260** and be coupled to electrodes **280** disposed on the cortical dura.

[0050] With reference to **FIGS. 2C and 2D**, lead securement devices **240** are shown. Lead securement devices **240** may include StimLoc devices available from ign. Lead securement devices **240** may minimize dislodgment of lead wires **220**.

[0051] Lead wires **220** may be coupled to the circuitry of the disc-shaped portion **210** by means of connectors **215**. Connectors **215** may include a plurality of male contacts **217** for providing electrical contact to corresponding female contacts of the circuitry (not shown). A screw hole **219** may be formed in the connector **215** for securing the connectors **215** to the disc-shaped portion **210** and for securing the disc-shaped portion **210** to the skull of the patient.

[0052] The circuitry may include a stimulation circuit **300** as shown in **FIG. 3** and a portion of the power circuit as shown in **FIG. 8A**. The stimulation circuit **300** may include a circuit printed onto the disc-shaped portion **210**. For purposes of illustration, the stimulation circuit **300** may be modeled using discreet components. The stimulation circuit **300** may include a PIC microcontroller **310** such as the PIC16LF87. The microcontroller **310** may manage the internal stimulation circuitry. A low frequency receiver chip **320** such as the ATA5283 may be coupled to the microcontroller **310** and may convert RF communications into programming commands which the microcontroller **310** interprets. An array of analog switches **330** such as the MAX4066 may be coupled to the microcontroller **310** and connect to voltage dividers **340** to output stimulation locations. Analog switches **330** may be coupled to electrodes **230** (**FIG. 2A**) and **260** (**FIG. 2B**).

[0053] According to internal parameters which can be modified via an external RF programming signal, the microcontroller **310** may control analog switch states to determine a voltage applied to any combination of four output locations including four output locations on electrodes **230** and **260**. The maximum possible voltage is determined by the supply voltage to the circuit **300**. A pulsing frequency, nominally 185 Hz, can be adjusted slightly as well as whether a stimulation pulse is applied or not. In order to conserve energy, the microcontroller **310** may enter a standby mode for 4 ms between pulses, greatly reducing power consumption. The microcontroller **310** may be operated with an internal clock frequency of 125 KHz, giving an efficient tradeoff between power conservation and proper functionality. This clock frequency allows pulse durations in increments of 32 micro-seconds. The output pulse duration can be adjusted between ~60 and ~180 microseconds. With reference to **FIG. 4**, **FIG. 5** and **FIG. 6**, the frequency output, varied voltage output and pulse duration of the microcontroller **310** are shown respectively.

[0054] Every pulsing cycle, the programming input from the low frequency receiver chip **320** may be checked. If a programming signal is present, an input code may be read

sequentially and the specified parameter adjusted to a new value, after which the program continues its pulsing routine.

[0055] The low frequency receiver chip **320** used for receiving external programming commands uses an amplitude shift keying (ASK) protocol. The state of a 125 KHz signal being received determines the output voltage of the low frequency receiver chip **320**: on-high, off-low. While waiting for a signal, the low frequency receiver chip **320** may remain in standby mode, conserving power. Upon the presence of a programming signal, the low frequency receiver chip **320** may wake up and send the coded data to the microcontroller **310**, after which the microcontroller **310** may tell the low frequency receiver chip **320** to enter standby mode again. The programming signal may include a preliminary "on" time to wake up the low frequency receiver chip **320**, a 4-bit header, a 3-bit parameter identifier, and a 4-bit data value. Each bit time is 2 milliseconds, allowing enough time for the microcontroller **310** to process the bit reception before the next bit arrives. An antenna attached to a coil input of the low frequency receiver chip **320** may be a short wire having a strong programming signal.

[0056] Eight analog switches **330** may be used to control the output pulsing. Four switches **330** may determine a path of the selected voltage to the four possible output locations. Each of these may be controlled by one of the microcontroller outputs, which are in turn enabled or disabled depending on the internal variable for output locations. The inputs of the four switches **330** may be attached to the outputs of the other four switches **330**. The inputs of these four switches **330** may all be attached to different voltage dividers **340**, providing four different voltage levels, ranging from three quarters of the supply voltage to the supply voltage maximum of 3V. Each switch **330** may be controlled by an individual microcontroller signal, which also drives the voltage divider **340** for its particular switch **330**. For every pulse, only one of these four microcontroller signals is active, enabling the voltage from its divider **340** to be sent to the output switches **330** and ultimately to the electrodes **230** and **260**. The use of static voltage dividers **340** to provide output voltage scaling may minimize power consumption. In an alternative embodiment of the invention, a custom digital-analog converter could be used to allow for a higher range of stimulation voltages.

[0057] When tested for power consumption, a ~1 Ω resistor was put in series with a powering circuitry described herein. The voltage measured across the resistor while in operation was approximately 17 μV, implying that the DC current required is ~17 μA. At a supply voltage of 3 V, this equates to a power consumption of 51 μW. If operated for 24 hours, the implant would consume a little over 4.4 Joules/day. Typical parameters of a stimulation signal provided for Parkinson's disease are a series of pulses of 120 microsecond duration, 2.5 volts in strength at a repetition rate of 185 pulses per second. Assuming these typical parameters, there are:

$$185 \text{ pulses/second}*60 \text{ seconds/minute}*60 \text{ minutes/hour}*24 \text{ hours/day}=1.5984*10^{7} \text{ pulses/day.}$$

With pulse duration of 120 micro seconds, this gives a total energy application duration of $1.5984*10^{7}*120*10^{6=1918.08}$ seconds. With 2.5 volts and 50 micro amps=120 micro watts, the total energy required for stimulation is $120*10^{6}$ watts*1918.08 seconds=0.2302 joules per day. As disclosed herein, energy harvesting by the power circuit is on the order of 12-15 joules per day and the stimulation energy required is more than adequately provided by the power circuit.

[0058] An external programmer circuit **700** may include a microcontroller **710** including a PIC16LF87, an inductor/capacitor (LC) oscillating circuit **720** (125 KHz), and an intermediate MOSFET driver **730** including a TC4422 as shown in **FIG. 7**. The MOSFET driver **730** may supply enough energy for driving the LC circuit **720**. When a programming signal is to be sent, a button (not shown) may be pressed, telling the microcontroller **710** to read its inputs and stimulate the MOSFET driver **730** to oscillate the LC circuit **720** according to a communication protocol. Input voltages may be controlled by simple switches. Four switches may dictate the value to be sent, while five switches may dictate which parameter is to be changed. Only one of these switches should be on at one time. A Phidget RFID antenna **740** designed for 125 KHz may be attached to the high voltage side of a capacitor **750** of the LC circuit **720** for sending the programming signal. The circuit **700** may be powered via a 12-Volt wall supply. The 12 V drives the MOSFET driver **730** and is regulated to 5 V for the switches and microcontroller **710**.

[0059] An external powering circuit **800** may include a battery **810** for powering an oscillator **820** which drives a transformer-like setup **830** as shown in **FIG. 8A**. The coils **835** on one side of the transformer **830** may be disposed in a cap worn on the head of a patient, a headband worn on the head of the patient, or on a headboard of a bed in which the patient lies. The coils **840** on the other side of the transformer **830** may be coupled to the stimulation circuit **300** and may be disposed proximate the coils **835**. An AC signal coming from coil **840** may be amplified and rectified through a charge pump **850** having three stages, after which a voltage may be clamped with a regulator **860** to prevent spiking. A control circuit **870** may control operation of the voltage regulator **860**.

[0060] The oscillator **820** may include an LTC6900. This oscillator **820** produces a 50% duty cycle square wave to drive the primary coil **835** of the transformer **830** and requires only a potentiometer for adjusting the frequency. The charge pump **850** may be a Cockroft Walton voltage multiplier, utilizing a ladder of diodes and capacitors to rectify and amplify the signal. The amplification depends on the number of stages used. Three stages have been found to be enough for a substantial voltage multiplication across a load of 200 KΩ. The capacitors may be 0.1-μF each and the diodes may include BAT54SW surface mount diodes with a forward voltage drop of ~0.24-V. The regulator **860** may include an LT1521-3, which clamps a higher input voltage to 3 V.

[0061] Previous empirical testing showed square coils (both primary **835** and secondary **840**), 1 in.×1 in., with 5 turns each are effective for transferring enough energy to power the stimulation circuit **300**. Coils **840** are shown in PCB layout in **FIG. 9** and coils **835** are shown in PCB layout in **FIG. 10**.

[0062] The optimal frequency depends on the dielectric and distance between coils **835** and **840**. Frequencies in the range of 2 MHz to 15 MHz may be used. The oscillator **820** can be powered with 3 AAA batteries (4.5 V). In examining

the actual signal through the primary coil **835**, the voltage waveforms in **FIG. 11** and **FIG. 12** were obtained. **FIG. 11** shows the output voltage from the oscillator **820**. **FIG. 12** shows the voltage across the primary coil series resistance, from which the RMS current is calculated to be 29.36 mA_{RMS}.

[0063] The embodiment described above provides for near field harvesting and includes inductive coupling between coils **835** and **840**. With reference to **FIG. 8B** and in an alternative embodiment of the invention, the power circuit **865** for powering the stimulation circuit **300** may be non-inductively coupled to an external source of RF energy **880**. In this far field embodiment, the power circuit **865** may be disposed in a wrist band worn by the patient, in a room transmitter or in a transmitter disposed in a building occupied by the patient. In yet another alternative embodiment of the invention, the power circuit **865** may harvest ambient RF energy such as energy transmitted in space by using an inherently tuned antenna as described in U.S. Pat. No. 6,856,291, the description of which is incorporated by reference in its entirety herein. Furthermore, a rechargeable battery or other storage device (not shown) may be employed to store harvested energy. "Non-inductive" as described herein being directed RF.

[0064] To demonstrate the effectiveness of the powering and programming schemes through tissue, the device **200** was tested through swine skin. Clear tape was used to cover the conductive surfaces on the primary coil **835** and the secondary coil **840** to prevent interaction with the moisture on the skin. This tape had negligible effect on the inductive coupling.

[0065] Three different tests were performed, each following the same procedure. At a certain separation, the voltage powering the primary coil oscillator **820** was adjusted and the maximum output voltage from the secondary coil voltage regulator **860** was measured. The primary coil oscillator voltage started at 5 V and was decreased in increments of 0.1 V until the maximum regulator output voltage had reached a steady minimum.

[0066] The first test was performed with no skin between the transformer coils **835** and **840**. Data was acquired at separations of 5 mm, 7 mm, and 10 mm, values chosen based on the common range of human scalp thickness. The second test used fresh swine skin of thicknesses 5 mm and 7 mm between the transformer coils **835** and **840**. The test was interrupted, preventing the testing of 10 mm thick skin. The third test used the same pieces of swine skin, 5, 7, and 10 mm thick, after they had been frozen and thawed.

[0067] **FIG. 13** shows the results from the first two tests for comparison purposes. The presence of the skin reduced the inductive coupling between the coils, and hence the possible maximum output voltage in the range of 1.5-3.8 V. At 4.0 V and above, the maximum output voltage of ~3 V is obtainable even with the presence of the skin.

[0068] The same pieces of skin were tested a second time due to interruption of the first test. However, they had all been frozen and thawed in the interim, affecting the results slightly. **FIG. 14** shows the effect that the freezing and thawing of the skin had on the energy transfer of the transformer coils. Both the 7- and 10-mm thick pieces of skin reduced the inductive coupling, but the 5-mm skin actually improved in performance. This may be due to the presence of a layer of fat in both the 7- and 10-mm pieces that is absent in the 5-mm piece.

[0069] Another test was performed to find the effect of the skin over time. The stimulus for this test was the degrading performance of the 10-mm thick skin over time during the interrupted test mentioned above. For this test, the 7-mm thick piece of skin was used between the primary and secondary coil. The frequency was adjusted to produce a maximum output voltage, which was measured successively over a period of time. The results shown in **FIG. 15** support the fact that performance does not degrade over time. The slight drop in output voltage is likely due to the mechanical nature of the frequency-tuning potentiometer. Notice that the output voltage reaches a steady value and remains constant after that point.

[0070] In order to demonstrate the concept and functionality of the device **200**, a model **1600** was created as shown in **FIG. 16**. The stimulation circuit **300** was put on top of a Styrofoam head **1610** with wires running down through the bottom for power- and pulse-monitoring purposes. An ABS Plastic cap (not shown) was made to simulate the head's scalp, covering the stimulation circuit **300**. The primary powering coil **835** with the batteries **810** was secured in a hat **1620** over the position of the stimulation circuit **300** to provide for near field inductive coupling.

[0071] The device **200** was tested on a cadaver head to show that a signal may be generated through the scalp and to demonstrate the programmability of the device **200** during stimulation. First, an incision was made in the scalp of the cadaver head. The secondary coil **840** was inserted and placed on the skull and the incision was sewn, leaving the lead wires **220** of the circuit exposed. Six wires were used on the implanted circuitry, four representing the electrodes **230**, which were connected to an oscilloscope and two wires for power and ground. The primary coil **835** was then taped on the scalp directly on top of the implanted circuitry and connected to a power supply.

[0072] The experiment began by demonstrating the programmability of the stimulation circuit **300**. Four parameters were varied and displayed on the oscilloscope; pulse width (60, 120 and 180 micro seconds), amplitude (2.34V, 2.75V, 2.94V, 3.13 V), frequency (191 and 194 Hz) and the shifting from one stimulating probe to another (i.e. probe **1** to probe **2** or probe **1** to all four probes). A 10K OHM resistor was used to represent the brain resistance, however this resistance is higher than the resistance for the brain (900 to 1100 Ohms), but a 10 k Ohm resistor was used to ensure there was enough power.

[0073] Next, several voltages were tested to determine the output source voltage of the power circuit **865**. Initially, the power supply connected to the primary coil **835** was set at 5 V and was decremented by 0.1 V to 1.2 V. The voltage on the secondary coil **840** was clamped so as not to exceed 3V. As the voltage decreased on the power supply, the output voltage on the secondary coil **840** was steady at 3 V until it declined around 2.2 V. Once the voltage decreased from 3V, a potentiometer was adjusted to obtain the maximum voltage. The data obtained shows the when the voltage drops, the amplitude voltage and frequency drop off as well.

[0074] The device for brain stimulation using RF harvesting of the present invention provides a brain stimulation device that requires a single implantation site and surgery to thereby reduce both the cost and trauma to the patient of the implantation procedure. The brain stimulation device further uses RF energy as a power source to eliminate the need for a battery implanted in the pectoral area of the patient. The brain stimulation device further converts RF energy and

stores the converted RF energy for use in stimulation of targeted brain areas. The brain stimulation device is flexible and implantable under the scalp to minimize discomfort for the patient.

[0075] The foregoing description of the embodiments of the invention has been presented for the purposes of illustration and description. It is not intended to be exhaustive or to limit the invention to the precise form disclosed. Many modifications and variations are possible in light of the above teaching. It is intended that the scope of the invention be limited not by this detailed description, but rather by the claims appended hereto.

TABLE 1

Indication	Prevalence	Reference for Prevalence
	FDA Approved Indications	
Essential tremor (1997)	1.5–3% population	Am J Med 115:134–42, 2003
Parkinson's (2002)	1% of population > 50	
Dystonia (2004)	~150,000 in US	Mov Disord 3:188–94, 1988
	Current Clinical Trials	
Obsessive-compulsive disorder	2–3% of population	J Clin Psych 53 Suppl: 4–10, 1992
Tourette's syndrome	~1–2% children	J Psychosom Res. 55:3–6, 2003; Can J Neurol Sci Suppl 1:S64–71, 2003
Intractable epilepsy	~100,000 in US	Neurology 56: 1445–52, 2001; Rev Neurol (Paris); 160 Spec No 1:5S31–5, 2004
Intractable depression	1,000,000	Psychiatr Clin North Am 19:179–200, 1996; http://www.mhsource.com/depconsult/june 2004.jhtml?_requestid = 605984

We claim:

1. A system for brain stimulation using radio frequency harvesting comprising:

a device implantable under a scalp of a patient, the device comprising a radio frequency harvesting power circuit and a stimulation circuit; and

at least one electrode coupled to the stimulation circuit, the at least one electrode providing brain stimulation to targeted areas of the brain.

2. The system of claim 1, wherein the device is fabricated from a biocompatible substrate.

3. The system of claim 1, wherein the device is flexible and conformable to a shape of the scalp.

4. The system of claim 1, wherein the power circuit comprises a charge pump inductively coupled to a primary coil of an external power circuit.

5. The system of claim 1, wherein the power circuit comprises an inherently tuned antenna for harvesting energy transmitted in space.

6. The system of claim 1, wherein the at least one electrode provides deep brain stimulation.

7. The system of claim 1, wherein the at least one electrode provides cortical stimulation.

8. The system of claim 1, further comprising a programming circuit operable to control the stimulation circuit.

9. The system of claim 8, wherein the programming circuit is operable to control a stimulation circuit voltage output.

10. The system of claim 8, wherein the programming circuit is operable to control a stimulation circuit output pulse width.

11. The system of claim 8, wherein the programming circuit is operable to control a stimulation circuit output frequency.

12. The system of claim 1, further comprising an energy storage device coupled to the device.

13. A system for brain stimulation comprising:

a device implantable under a scalp of a patient, the device comprising a coupled power circuit and a stimulation circuit; and

at least one electrode coupled to the stimulation circuit, the at least one electrode providing brain stimulation to targeted areas of the brain.

14. The system of claim 13, wherein the coupled power circuit is inductively coupled.

15. The system of claim 13, wherein the coupled power circuit is non-inductively coupled.

16. A system for brain stimulation comprising:

a device implantable under a scalp of a patient, the device comprising a power circuit powered by ambient radio frequency energy and a stimulation circuit; and

at least one electrode coupled to the stimulation circuit, the at least one electrode providing brain stimulation to targeted areas of the brain.

17. The system of claim 1, wherein the at least one electrode provides brain stimulation to targeted areas of the brain in response to signals received from the stimulation circuit.

18. A method of providing brain stimulation, comprising:

harvesting power in a power harvesting circuit in a device implantable under the scalp of a patient; and

providing brain stimulation to targeted areas of the brain with at least one electrode connected to the power harvesting circuit.

19. The method of claim 18, wherein the power harvesting circuit harvests radio frequency energy.

20. The method of claim 18, wherein the power harvesting circuit harvests energy by an inductively coupled power circuit in the device.

21. The method of claim 18, wherein the power harvesting circuit harvests energy by a non-inductively coupled power circuit in the device.

22. The method of claim 18, wherein the brain stimulation is used to treat Parkinson's disease.

23. The method of claim 18, wherein the brain stimulation is used to treat stroke patients.

* * * * *

AWSH.ORG

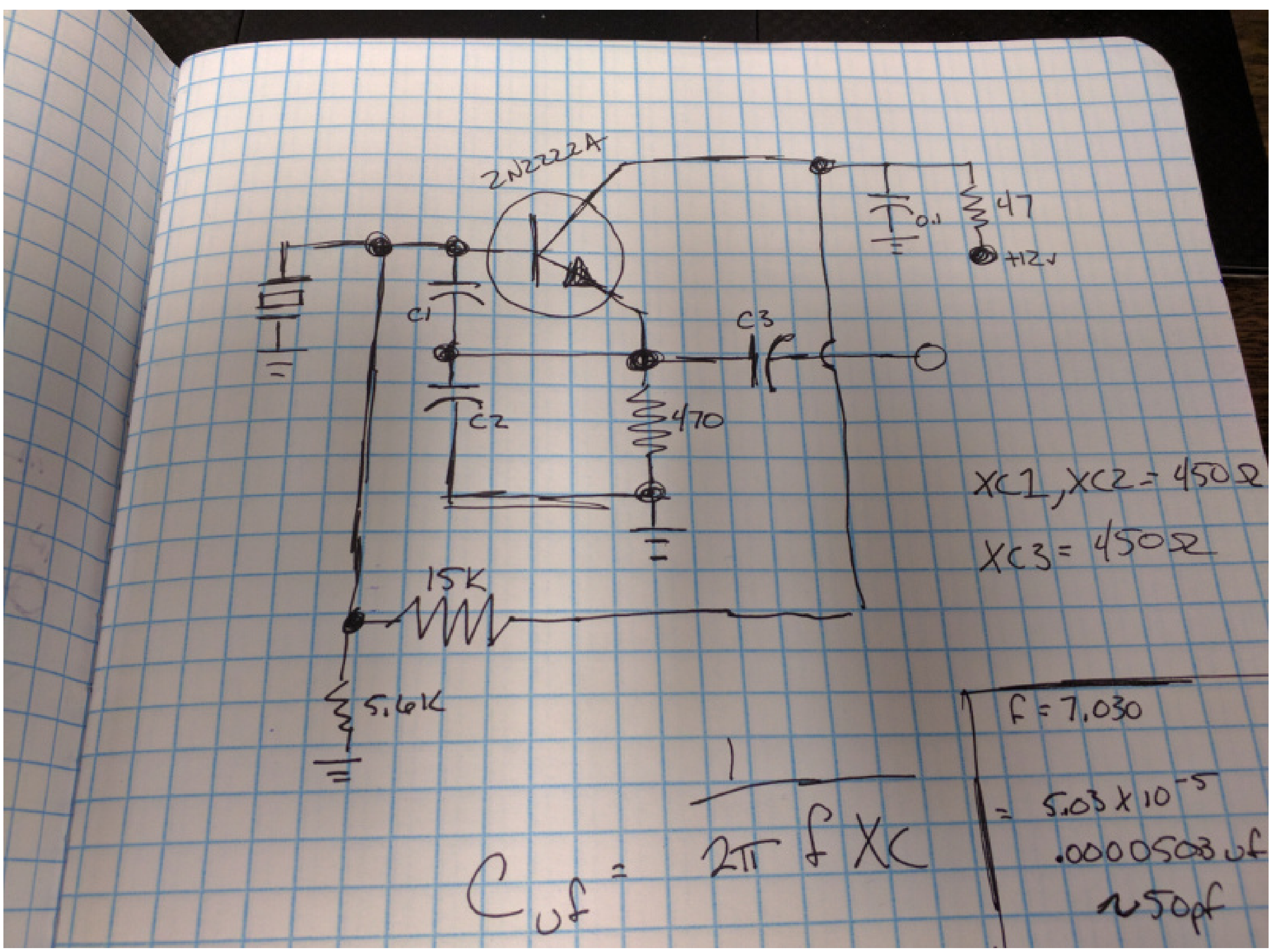
stuff that i do and things that i make

oscillators

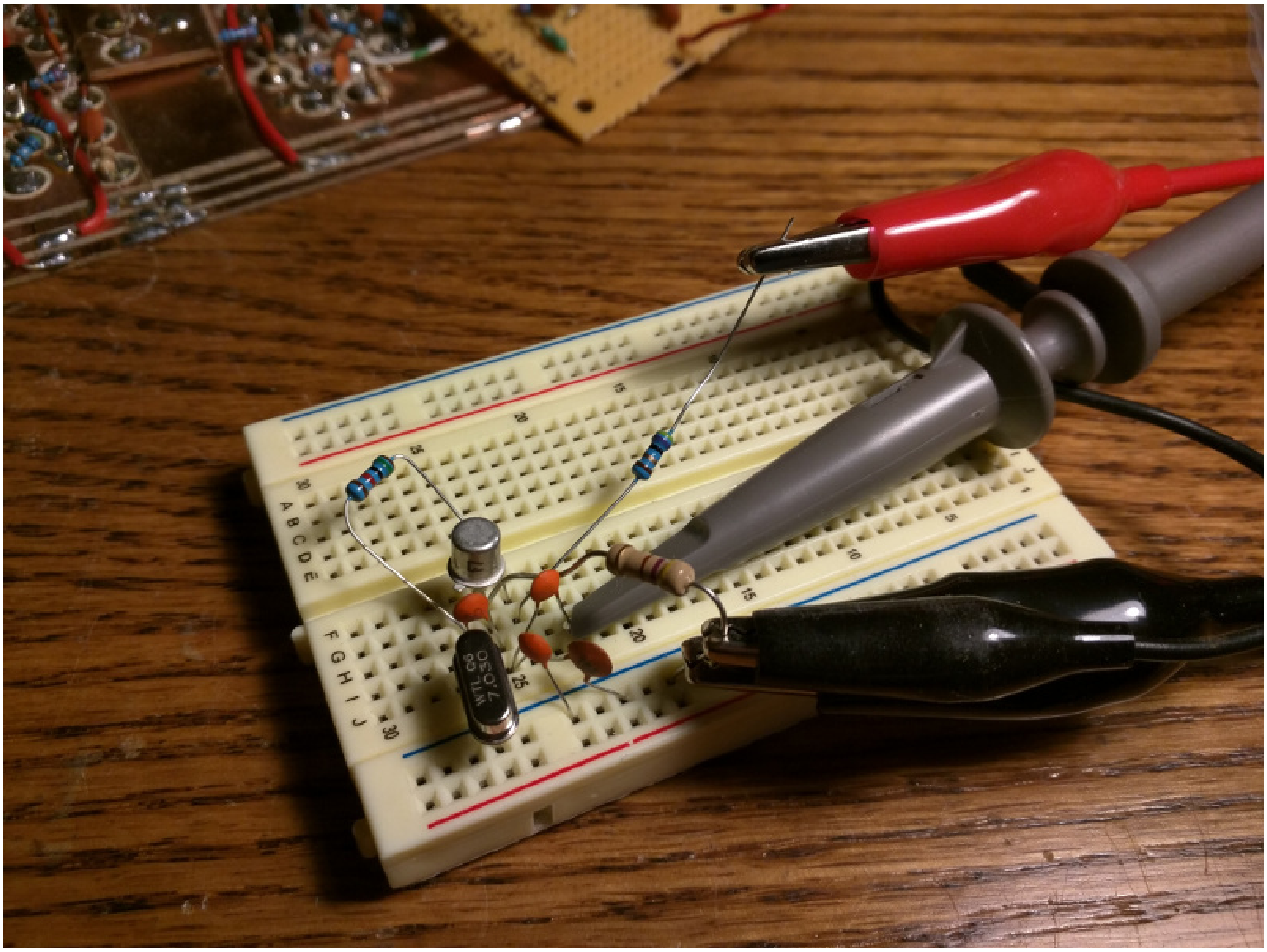
PUBLISHED JULY 7, 2017

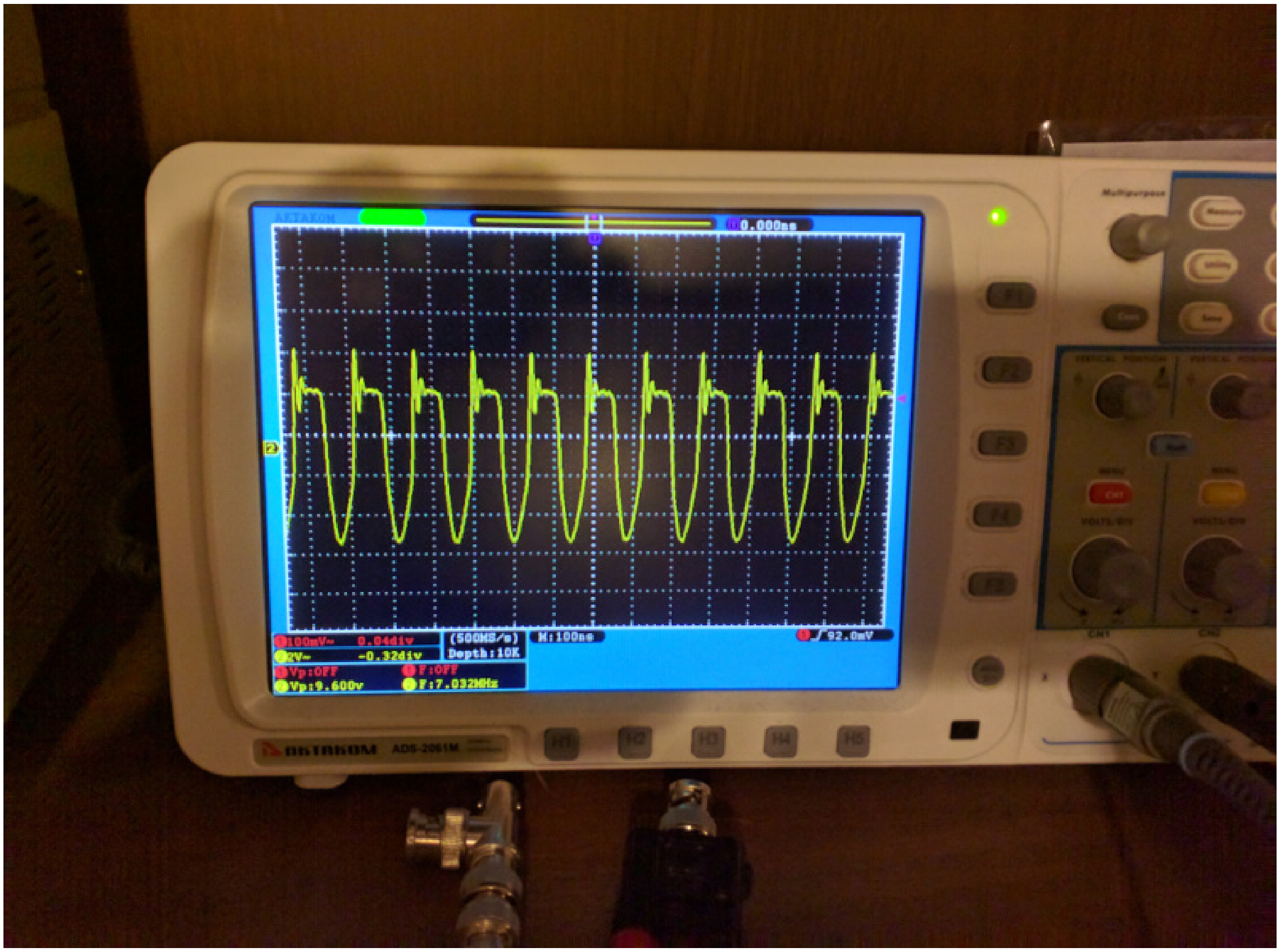
I've been reading some older qrp circuit design books and wanted to play around with some of the oscillators. With the audio amp from a recent post, I may have the start of a little qrp receiver or possibly a transceiver.

I started with a simple colpitts oscillator. The schematic below is what I used. For the capacitors, you can see the capacitive reactance to the right. Using the formula at the bottom, you can calculate the capacitor values for the desired frequency. I used a 7.030 crystal, so the capacitors came out to 50pf.



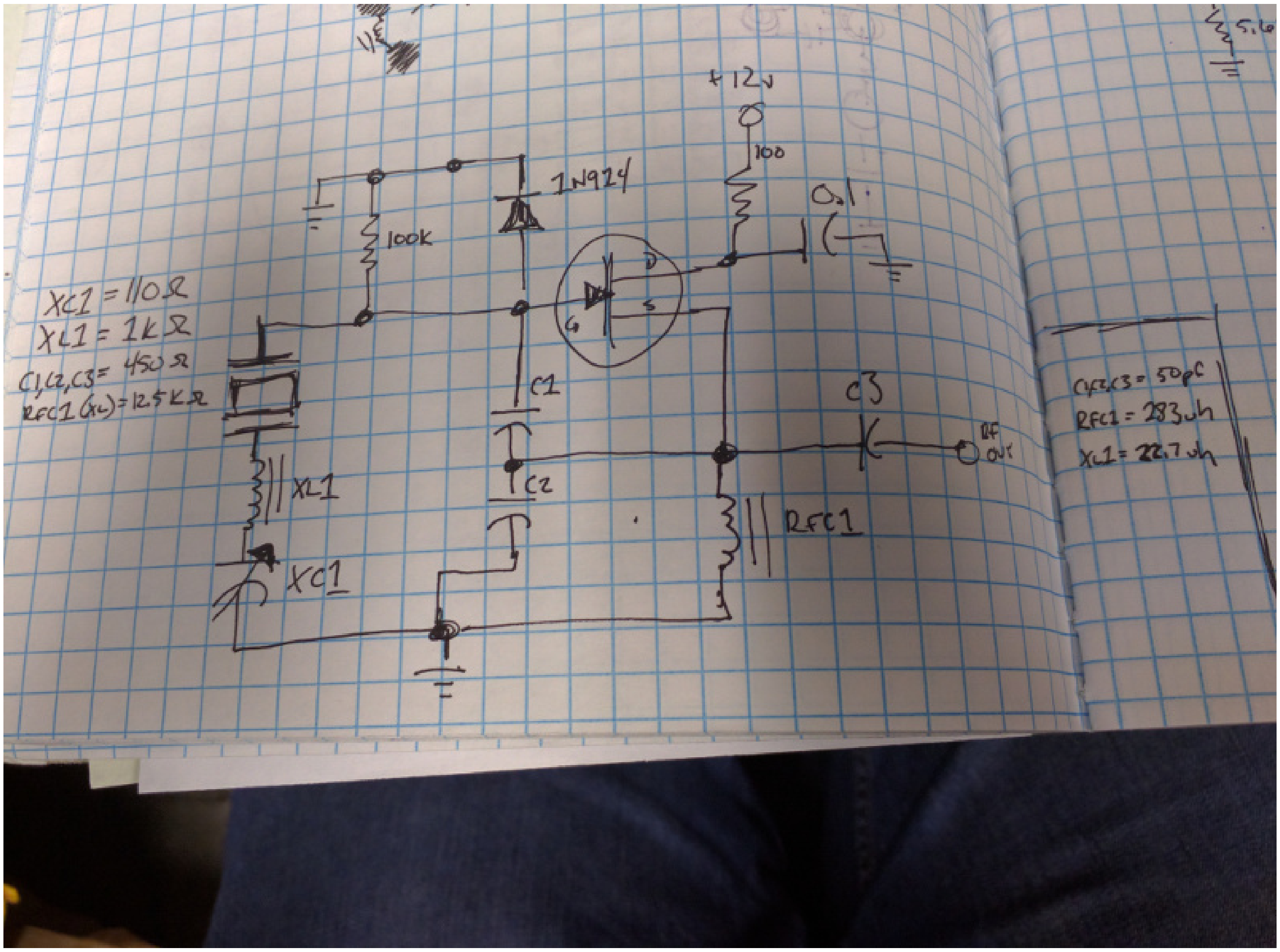
I built the circuit on a breadboard and had a pretty ugly waveform from it, but this was more or less for experimentation rather than any practical use.



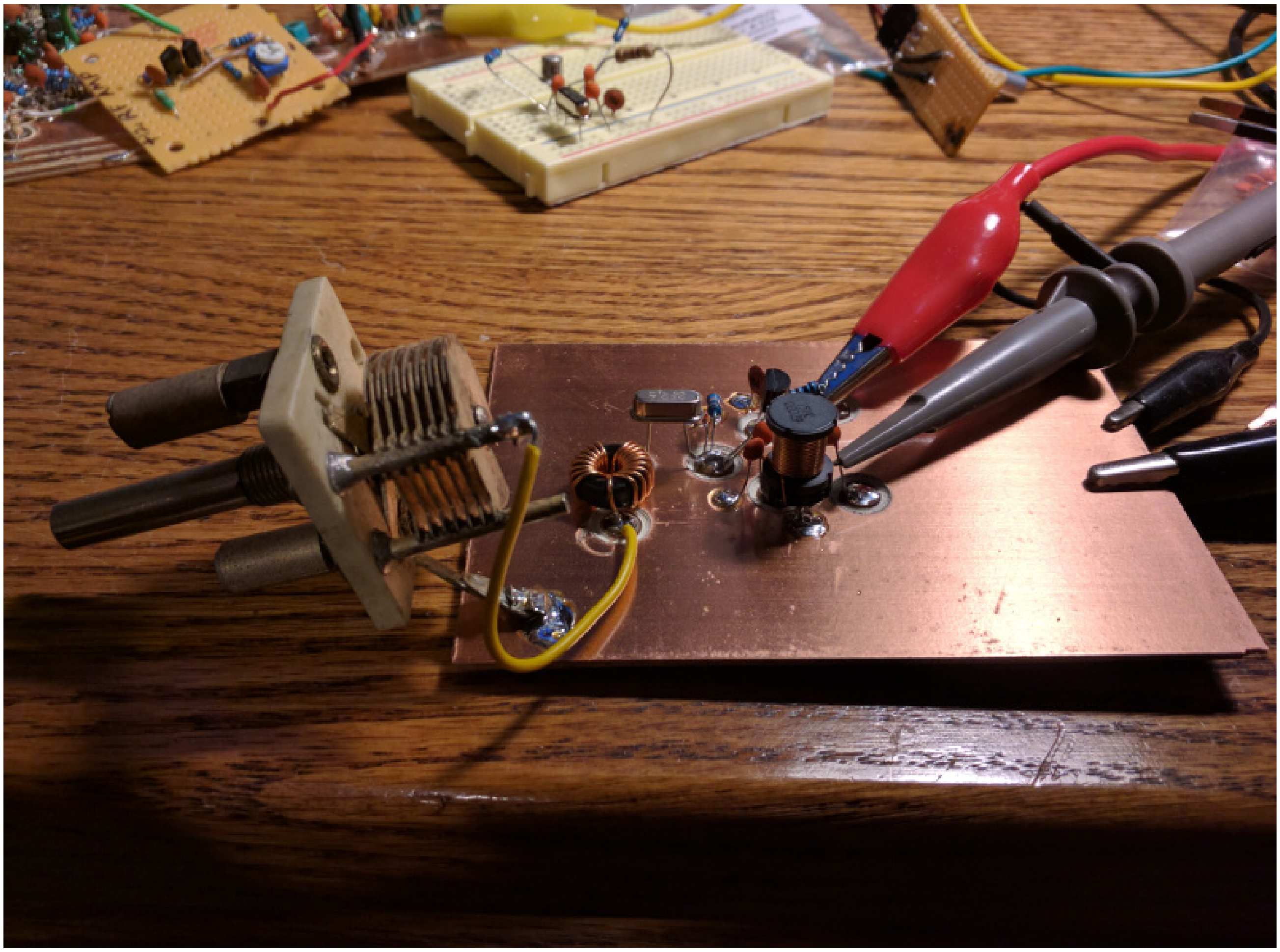


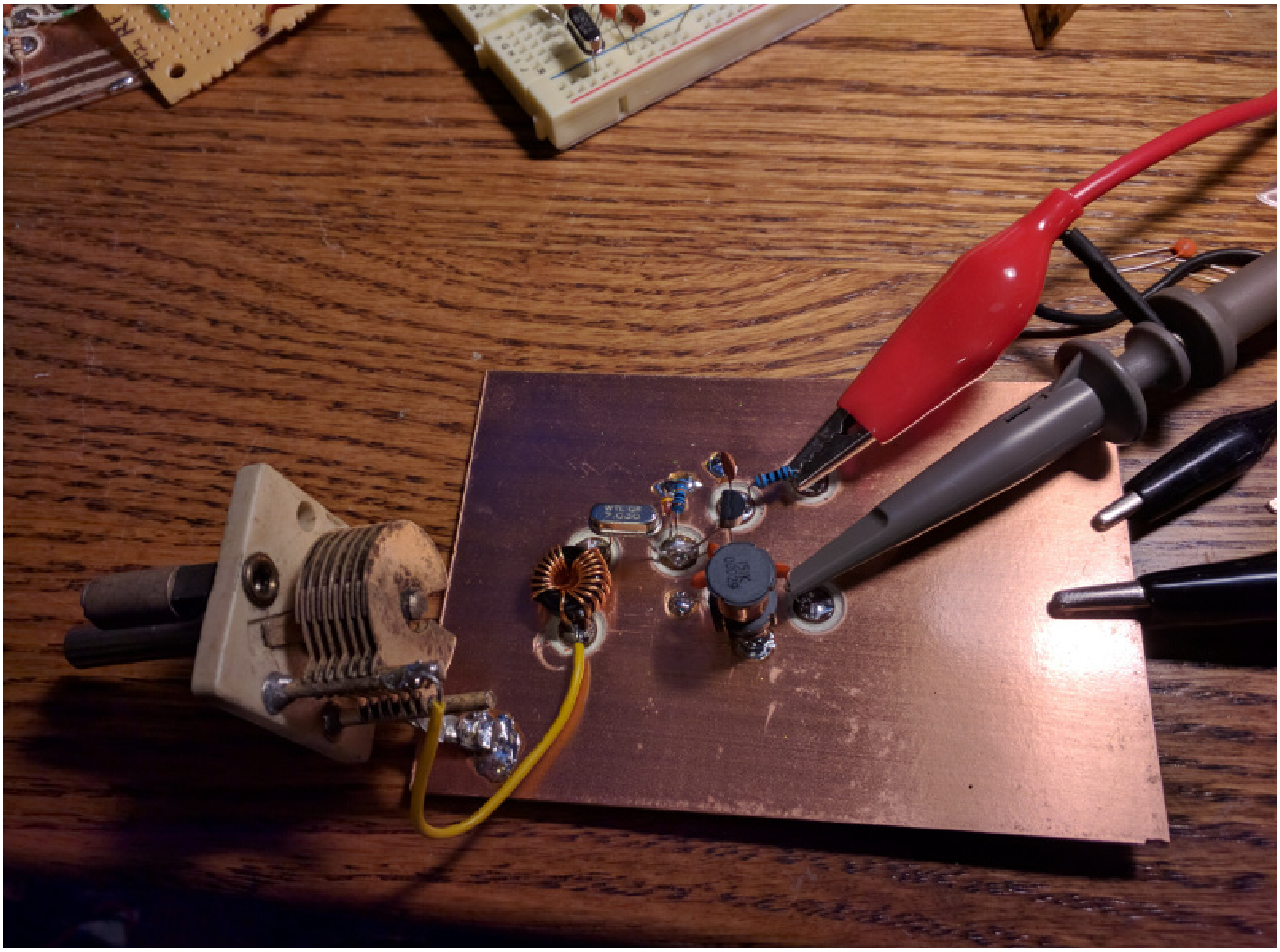
Next, I went for a vxo that followed the colpitts design. The same formula from before can be used for this schematic. For the inductors, you can use the formula, [inductance in uH = XL / 2 * π * (frequency in MHz)]

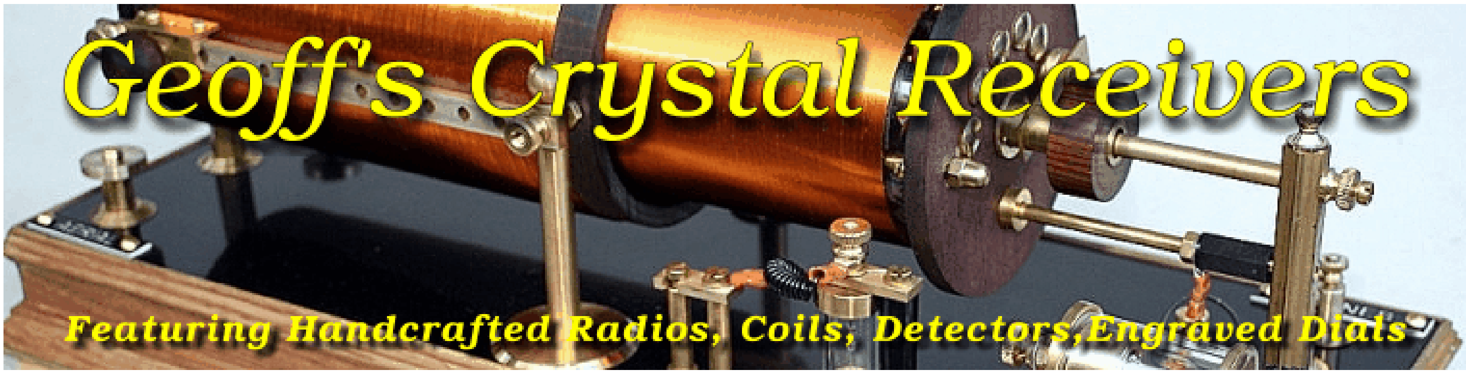
I used a 7.030MHz crystal again, so my capacitors came out to 50pf, and the inductor RFC1 = 283uH, and XL1 = 22.7uH. The closest I came with RFC1 was a 150uH coil, so I went with that and it worked okay. I don't think the values for the components are super critical so some experimentation is probably a good thing. I used a J310 for the jfet at the center of the oscillator and the rest of the components I used as listed in the schematic.



I just grabbed a random air variable cap. I didn't even measure it, but the circuit works pretty well. My scope has a pretty bad frequency counter in it, but it showed that this vxo could pull the crystal frequency about 10kHz. I'll try to hook up a better frequency counter and see if I can get a more accurate measurement this weekend.







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Geoff's Crystal Sets – Page 2

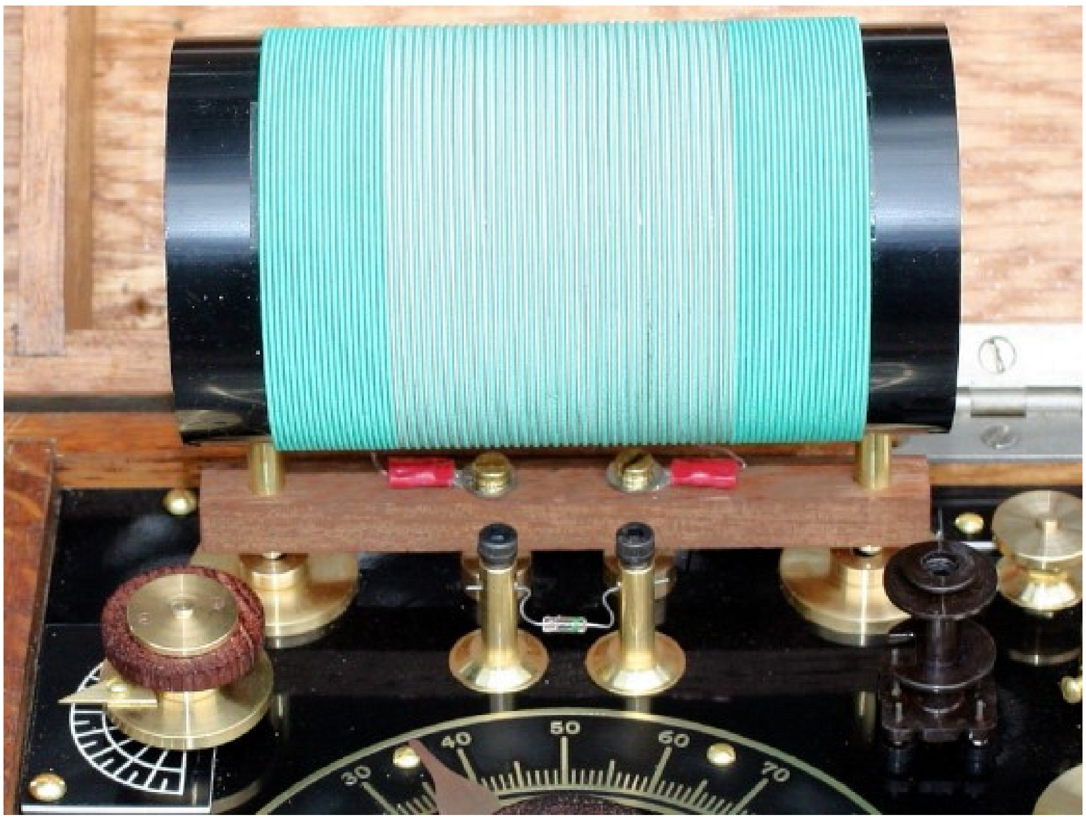
Heart of Oak Crystal Receiver

Please click on the photographs for a larger picture of this beautiful wireless receiver.

Order Nr. *Heart of Oak Crystal Radio*

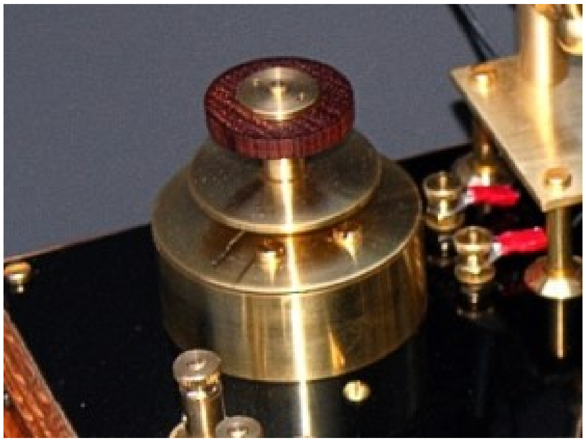
I made this set in 2010 with two intentions in mind one was to go portable with it for use on holidays in the caravan or on camping field days with the ham radio station and a telescopic mast and dipole aerial. The other use was as a test receiver for various components and coils. The main coil and AF Choke coils are plugable. This was again a 'Mystery Crystal Radio' circuit so the main coil has four connections on the base . The Box was made from solid English Oak with comb jointed corners. This was the usual traditional form that the early set makers used in their box construction. It is a very strong box and also was designed to house the headphones and a couple of spare coils in the separate compartment. I intended to make a handle from a piece of Natural Veg leather which would be double handstitched to give it some extra strength.This set is still an ongoing project and I may fit brass edge trim to the box corners at a later date. I will put a tuning scale chart into the lid calibrated in frequency against the 0-100 logging scale.

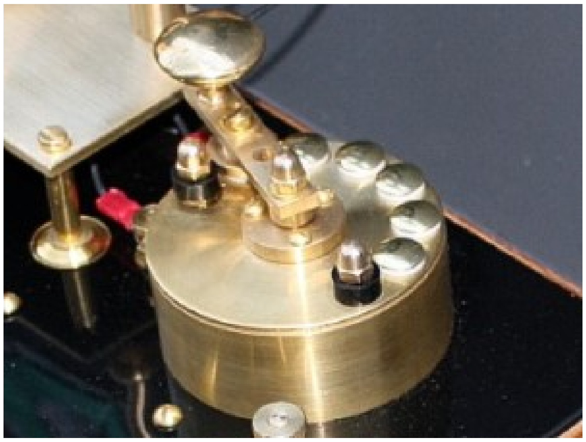
This set was used at the 'Tate Britain' exhibition 'Restless Times' in which I exhibited a number of crystal sets in September 2011 and the set was really the main one used in the demonstration of sounds from a crystal radio in the 'Duveen Gallery' exhibition



Jules Verne Mk. 2


CRYSTAL-RECEIVER.CO.UK





Order Nr. *Jules Verne Crystal Radio Mk. 2*

Dual Slider with Perikon Detector

If you could fall in love with your electro mechanical creations like your own offspring then this radio comes close.

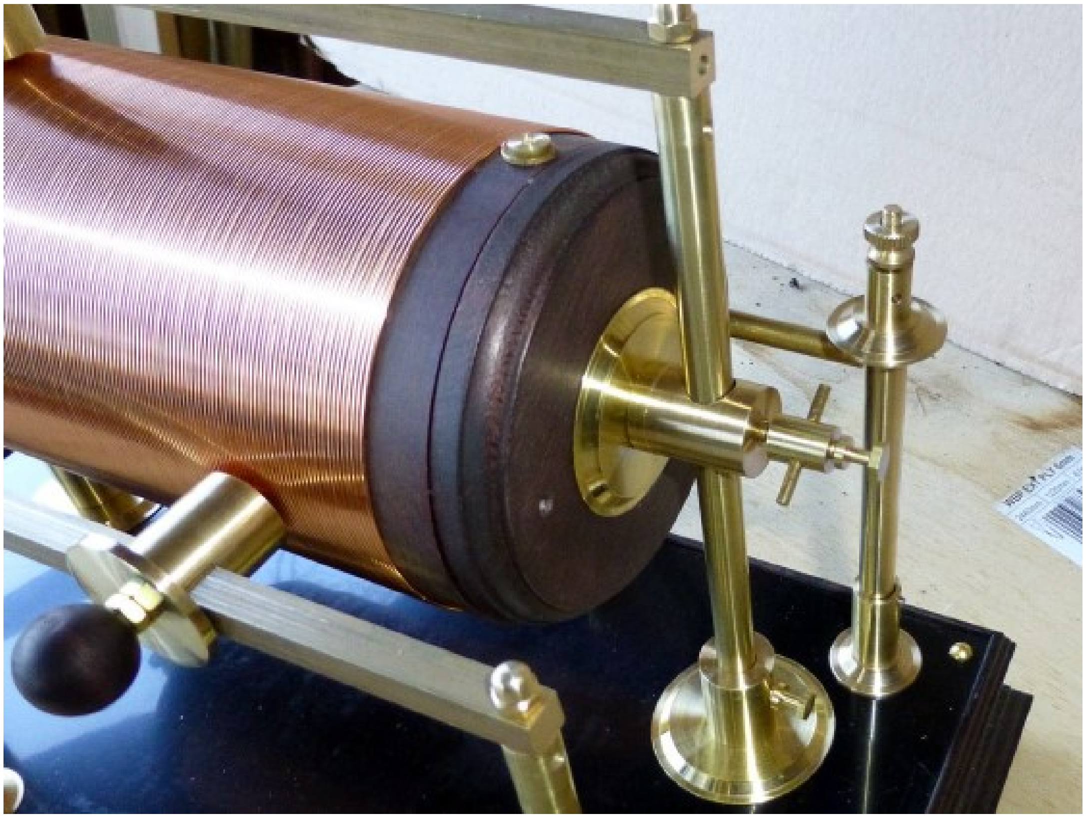
Beauty simplicity and purity are the words that come to mind when this project was completed.The idea was born when I was contacted by Julian Oliver Artist and Curator for his exhibition at the Phoenix Art Complex in Leicester . He gave me an outline of what he wanted. A set from the origins of radio and around the WW1 period for his project to do with the evolution and origins of modern communications in warfare. He suggested a dual slider however this was not exactly as the military time period for the WW1 but a little later and probably was designed for the commercial radio broadcasting era supported in the UK by the BBC in the early 1920's. However it was a visually appropriate balance of design from around the time period. The Military Crystal receivers were quite complex even in WW1 with military tuning capacitors and many switched coils not available in mass production for commercial receivers at the time. It would be impossible for me to reproduce for this exhibition in the very short time scale of a coupe of weeks that I had to complete the set.So I started the project and burnt the midnight oil on this one. It turned

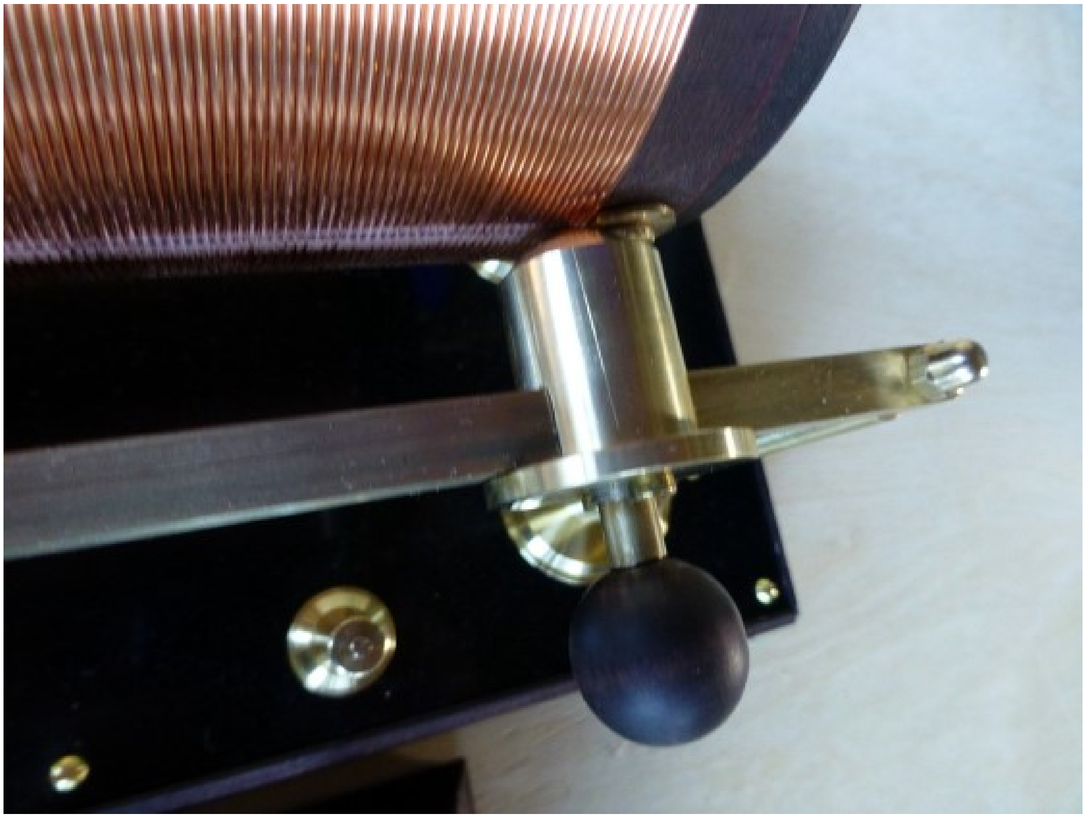
out lucky for Julian and I was able to find a really nice piece of Zincite on eBay with just the right properties that I was looking for, ie a reddish orange crystal with a point for the 'Perikon Detector' a bit more about the detector later.

The principle behind the operation of a 'Dual Slider crystal radios is rather simple in concept as it is just a coil of large inductance in this case 1000µH. Tuning is done by sliding a contact along the coil and this tunes in the station at some point along the coil. Tuning is quite broad but together with the earthy side slider tuning can be made sharper . There is no tuning capacitor to resonate the circuit other than stray capacitance from each winding and the interaction of the length of aerial to the gound or the set itself, at least that is the theory but these radio are strange and have an almost magical feel about them. Make the aerial longer or shorter and the point of tuning on the coil is different. It is beautifully simple and is surprisingly good but very hard to calibrate . I guess this was one of the reasons why they were eventually superseded by the Capacitor/Inductance tuned circuit that can be directly calibrated.

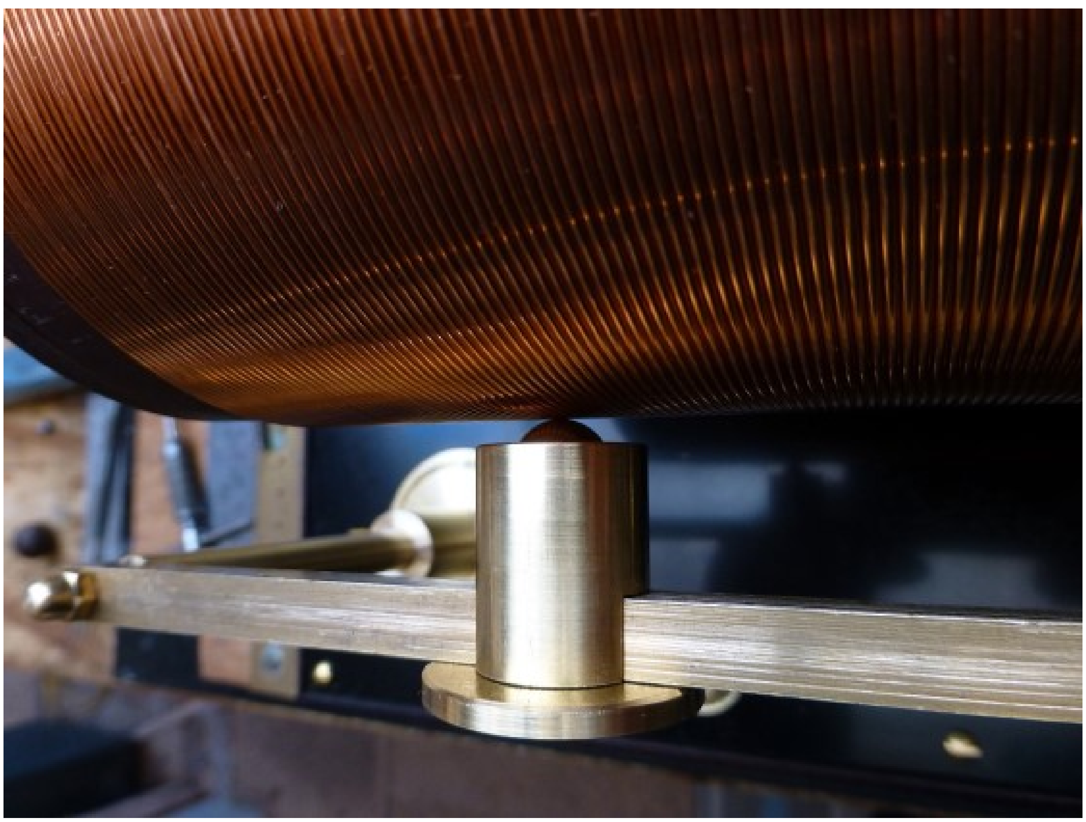
I have always been amazed how well these simple crystal radios actually work. Its seem as long as you keep to good radio practice by using the best materials ie Paxolin for the coil former and good quality wire with tight windings of at least 4 inches diameter coils they work well, cut any corners and performance drops right off.

This project worked very well and turned out to be a little feat of engineering that had great sculptural artistic qualities as well.





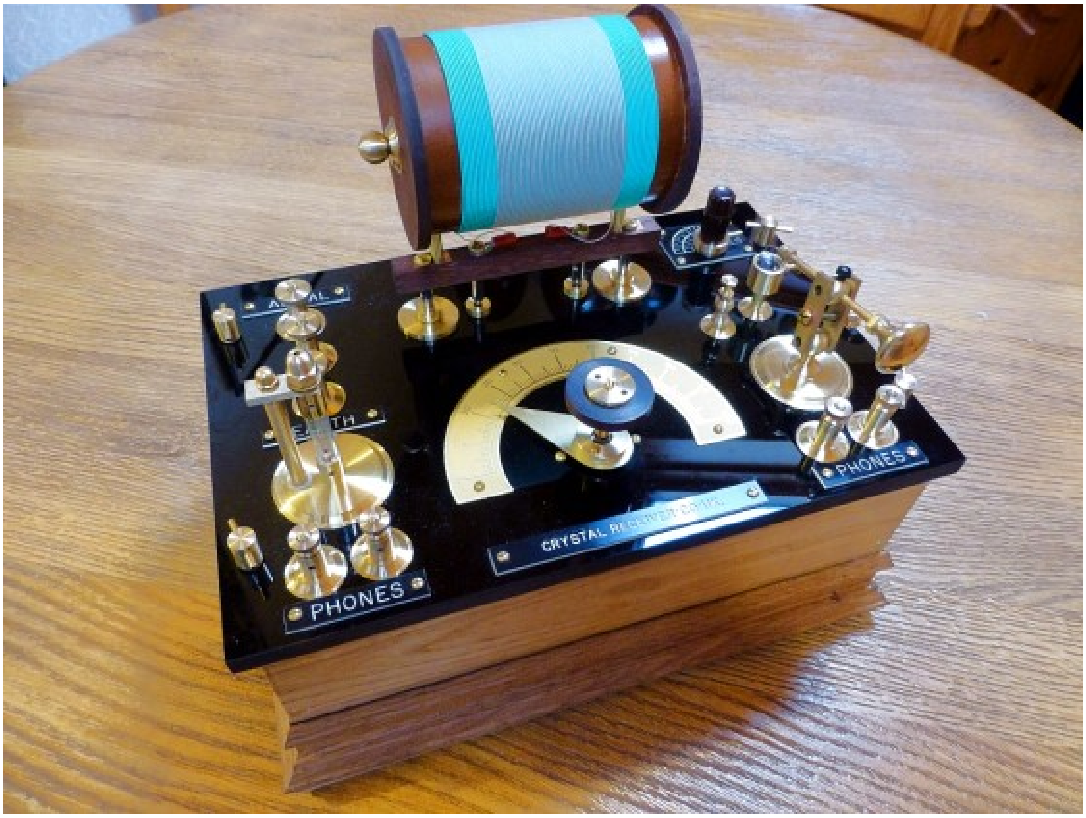
The Slider



The contact on the coil winding has to be a mechanically positive one ie, a very good electrical connection or noise will be generated when the slider is moved from one end of the coil to the other. On most vintage sets this is just a strip of springy metal usually of a Copper alloy containing Beryllium. This I guess was done for cheapness or fast production and it also wears out the coil wires much quicker and bridges too many wires.

A smoother and more engineered approach to this is to use a Phosphor Bronze ball in a socket and spring load this with a coil spring. It is so much smoother and noise less.

Mystery Set MK5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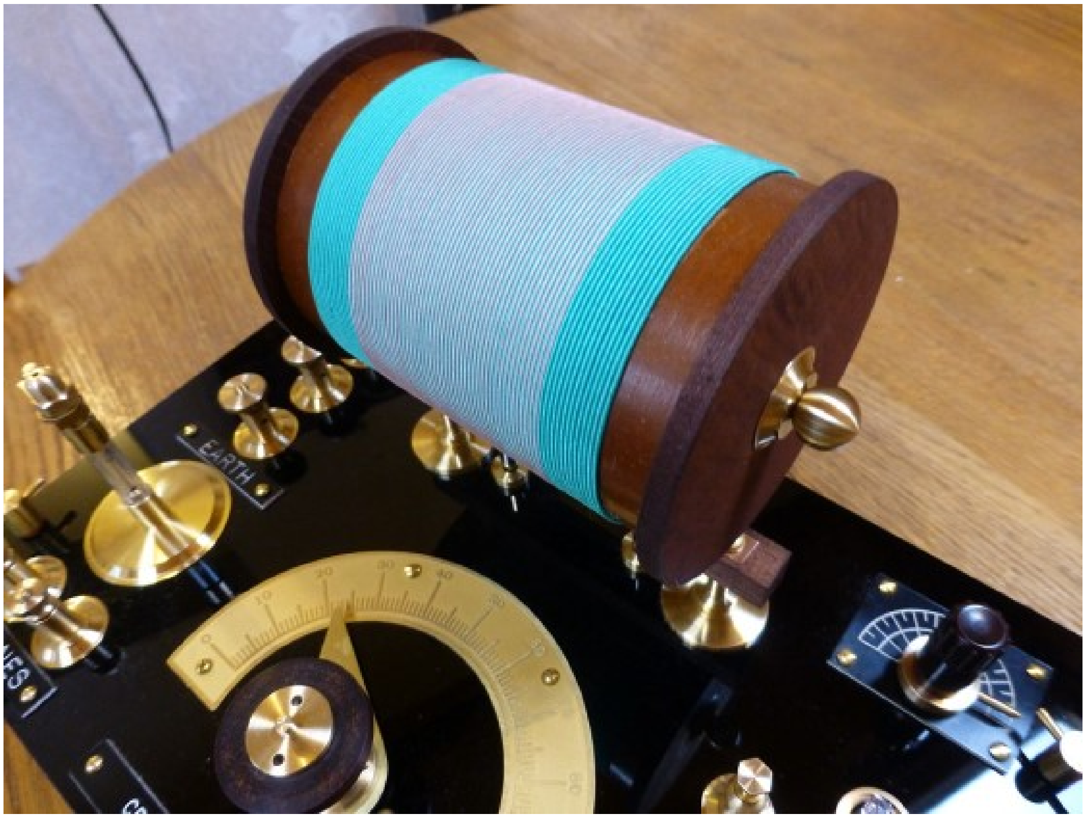


This is a receiver based on the Australian Mystery Crystal Radio design. It has more brass than the original Aussie design. This is the Mk5, S/N 13 design.

Hi Dave (the webmaster) I have decided to call the MK5 set *The Sgt Pepper Magical Mystery Crystal Set* , after the Beatles Album. Because its a Magical Mystery set that will blow you away. I need taking away too Hahaha.
Geoff

Geoff's Crystal Sets, Page 1

Geoff's Crystal Sets, Page 3

Aerial Parts | **Brass Hardware** | **Capacitors** | **Coils** | **Detectors** | **Diodes**
Engraved | **Links** | **Loose Coupler** | **Misc. Items** | **Projects** | **Radios** |**Radios-2**
Radios-3 | **Switches** | **Workshop**

Paul Harden, NA5N • na5n@zianet.com

Part 1

The Handyman's Guide to – HOMEBREW CONSTRUCTION PRACTICES From Copper to Manhattan

What is the difference between a QRPer and a Homebrewer? Not much, from what I have seen over the years. Where you'll find a QRPer, you'll generally find someone who loves to build his own equipment.

When it comes to homebrewing, there are two QRPer's that have set the standard (in my opinion). First is Bill Jones KD7S. Bill's homebrew gear, mostly crafted from ABS plastic, sets the standard that rivals professional equipment. Second is Jim Kortge K8IQY and his now famous 2N2/40 built *Manhattan style*. While this method of construction has been around for years, and many will argue who actually "invented" it, there is no doubt that Jim's 2N2/40 elevated it to a whole new level. The craftsmanship of these two master builders sets the standard many homebrewer's now strive to achieve.

Due to the continuing interest in these "build it from scratch" construction techniques, George Heron and Joe Everhart asked if I could prepare a basic guide for the **Homebrewer** based on some of the gear I have built or seen – which I am pleased to attempt. However, I make no pretenses that this is the complete guide to homebrewing. More precisely, it might be called *"Homebrewing Using Copper"* – and for good reason. Copper clad is readily available at hamfests and from many vendors (I get mine from Electronic Goldmine). Copper clad is very easy to work with, not only for the "circuit board," but for the construction of the enclosure and front and rear panels. It is also the main staple of "Manhattan Style" construction. And, best of all – it's fairly cheap!

I have used copper clad and Manhattan Style for many years myself, both for my QRP homebrewing, and prototyping circuits at work. Examples of both will be presented here.

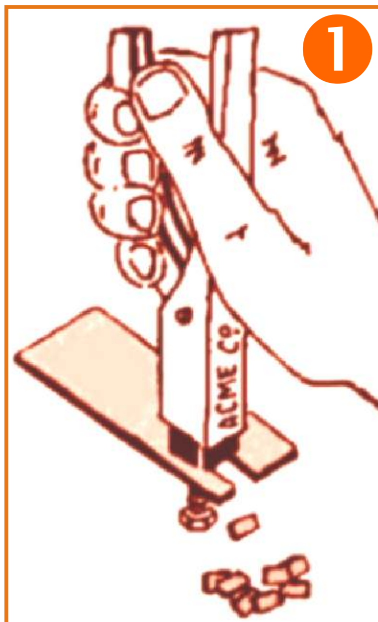
1. Let's Get Started . . .

MANHATTAN STYLE . . . What is it?

Simply put, ***Manhattan Style*** of construction uses small pieces of copper clad (the "pads") glued to the main copper clad circuit board (the "substrate") that serve as component mounting platforms. The electronic components are then mounted and soldered onto these pads. The main "substrate" board serves as the ground plane. Not only is this technique an easy and neat way to build a circuit, it also produces a very quiet circuit due to the solid ground plane.

When Jim Kortge, K8IQY, submitted his 2N2/40 at the FDIM building contest, one of the judges, Chuck Adams, K7QO, commented how the construction technique, with the IC's and electrolytic capacitors in neat rows, looked like an aerial view of Manhattan. Thus, Chuck is credited with dubbing it *Manhattan style* – the term it is well known as today amongst QRPers.

Making the "pads." There are numerous methods to make the pads. The most popular and easiest is using a ***nibbling tool*** to *nibble* out small pieces of copper clad from a larger piece, as shown in **Figure #1**. A nibbling tool costs $20 or less and used for making square cut-outs in 1/8" (max.) aluminum, such as for mounting a meter. The tool easy nibbles through .031" or .062" copper clad. The chards from the nibbling tool forms the pads, about 1/16" x 3/16". (Known as "chads" in Florida!).



Using a nibbling tool

Others make round or circular pads with a ***hand-punch*** tool from Harbor Freight or other sources. Dies of various sizes can be purchased for the hand-punch tool, with 3/16" or 1/4" diameter being popular sizes The tool punches-out holes in a piece of copper clad. The punched out material serves as the small, circular pads for Manhattan construction.

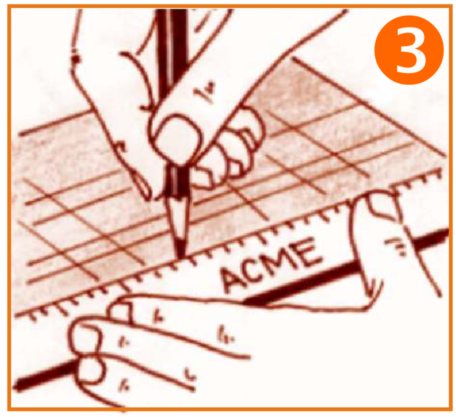
Still another method is to snap-off pads from a piece of ***perforated copper clad board*** as shown in **Figure #2**. The pads are twisted off with a pair of needle nose pliers or cut apart by a hefty pair of wire cutters. These pads are not as "pretty" as those made by a nibbling tool or circular hand punch, but work equally as well. The board can also be cut by following the perforated holes, using a coping or hack saw, to produce long strips, which can be cut-off at the desired length. One advantage of this technique is it allows you to make long strips that can serve as the +Vcc bus or making longer runs without having to connect two smaller pads with a jumper wire.

Using perforated copper clad circuit board for making the pads is another method, requiring no special tools.

Pads can be made from .031" or .062" thick copper clad, single sided or double sided.

Once the pads are made, it's a matter of placing them on the main circuit board for mounting the components. Before gluing on the pads, it is best to plan ahead.

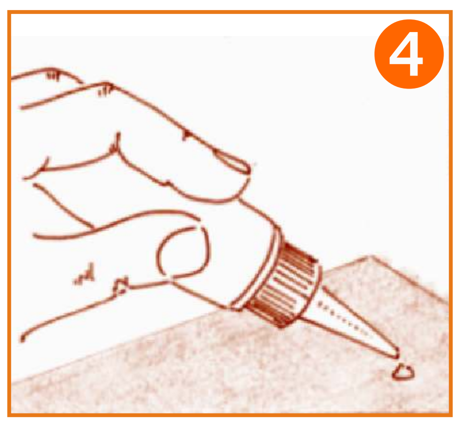
Laying out the circuit. It is recommended to lay-out your circuit on a piece of paper, arranging the components in a logical circuit manner, similar to laying out a printed circuit board with paper and pencil. This will ensure that all of the components will fit on the size of copper clad board you have selected as the circuit board or substrate. One can build Manhattan Style by "building as you go," but problems fitting components, working yourself into a corner, or ending up with long wire runs reaching front panel controls can occur. Planning ahead by laying out the circuit first is by far the best way to ensure the finished product is correct to the circuit, functional, and the final appearance is nice and neat.



Draw footprints of each section and guidelines with pencil on the copper clad board. Planning ahead is important!

Once this is done, transfer the layout to the copper clad board with a ruler and pencil as shown in **Figure #3**. This provides guidelines for gluing down the pads and keeping things straight, square and symmetrical.

Gluing down the pads. Once the circuit has been layed-out, it is time to mount the pads on the main substrate board with small drops of super glue, as shown in **Figure #4**. And, small drops is the secret! Learn to issue a very small drop, smaller than the size of the pad, to keep excess from being squeezed out over the board when you apply the pad. It takes a little practice, but you can learn to apply the right amount with little waste.



Pads are "mounted" to the main circuit board with glue – usually with super glue. The secret is learning to administer a small drop of glue. This comes with practice.

There are many opinions as to what type of super glue works the best. Some prefer one brand over another, some prefer the gels. I have tried them all and have found little difference between them other than personal preference. I build most of my Manhattan circuits with the cheapest glue I can find, which is usually Duro-Bond Super Glue, with two tubes per package costing $1.79 or less at Wal-Mart or local hardware stores. The small "snout" on the tube is also relatively easy to keep clean and open.

The biggest problem I have found with different manufacturers or with the exotic applicators is keeping them clean. They work great – the first time.

But, when you come back to work on the project the following night, that fancy $5 tube has super-glued itself shut. You either can't get the protective cap off, or the tube has turned into a solid brick. Time for a new tube. A couple of cheap tubes of super glue goes a long ways when this happens.

To avoid these problems, I usually do two things when I'm done for the day:

1) Remove the applicator tip and run a resistor lead down the spout to open up the channel from excess glue. The excess may run or drip out the end. This will ensure the applicator tip is "open" when you place the tip back onto the tube. Without doing this, the super glue left in the tip can turn solid and hard, preventing it from being used again.

2) Clean the applicator tip and protective cap with a Q-tip or paper towel soaked in alcohol or acetone. Clean off all access glue, particularly on the threads for the protective cap. Then, clean dry with a piece of paper towel. If the paper doesn't stick – it's clean! This will ensure you'll get the protective cap off the next time you use the tube of glue.

These two simple cleaning steps can keep a tube of super glue useful for a long time. If not, that's why the cheap tubes of super glue should be used.

Positioning the "pads." The pad is placed on the drop of super glue and positioned into exact placement with an Exacto knife or other sharp object, as shown in **Figure #5 and #6**. For the first few seconds, the super glue will be slippery, allowing the pad to be easily positioned. Once in the desired position, push down on the pad against the main board to squish against the glue. It will be solidly glued into place in a few seconds.

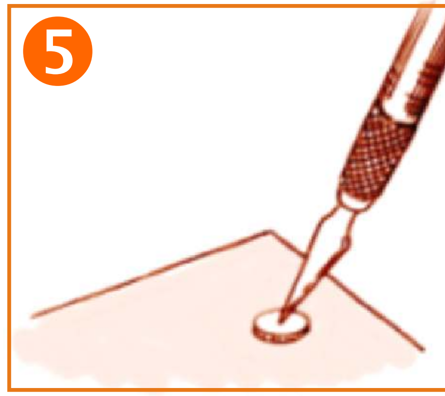
The method I often use is to place the pad into position with a pair of sharp, needle nosed tweezers. Once in position, I push down on the pad with a small screw driver or the wooden shaft of a Q-tip. However, the tweezer method does not work well when using the punched-out circular pads.

After several seconds, the pad should be firmly attached to the substrate board. Some of the circuits I have built years ago using this method have the pads still firmly affixed to the board.

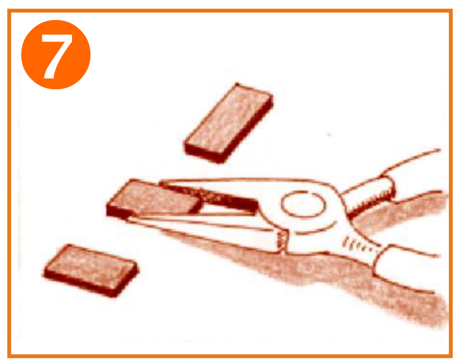
To remove a pad that got positioned in the wrong place, simply "twist it off" the board with a pair of needle-nosed pliers, as shown in **Figure #7**. Any pad that becomes dislodged from the board can be simply re–glued into place with a new drop of glue and holding in place for a few seconds.

Cleaning up. Once the excess glue had dried, it can be scraped off the board with a hobby knife or a small flat blade screw driver. It's up to the builder how picky one wishes to be with this. At a minimum, the board and pads should be cleaned with a hobby brush or toothbrush moistened with alcohol or acetate to remove oils, fingerprints and debris. This will make for easier soldering and a nicer appearance.

Acetone dissolves dried super glue better than alcohol. It is easily obtainable as fingernail polish remover in many stores. However, most fingernail polish remover sold today is "acetone free." Ensure you get a bottle that contains real acetone. I get a bottle of acetone based fingernail polish remover from Wal-Mart that works quite well. It costs 88 cents for a pint bottle and usually lasts for several projects.



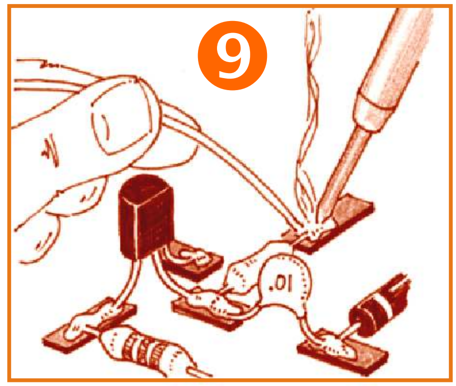
Place the pads onto the drop of glue and position with an Exacto knife, other sharp object or tweezers..



Remove a pad by a twist with a pair of needle-nosed pliers.

Clean board and pads with a brush and alcohol or acetone.

Melt solder! Once the pads are in place and cleaned, there is nothing left to do except mount the components onto the pads and solder in place according to the layout drawing. Of course, ground connections are soldered directly to the main substrate board, being the circuit ground plane, as shown in **Figure #9**.



The glued pads become the mounting platforms for the components, soldered in place.

I use a small hobby brush with hair or fiber bristles (not steel) for cleaning the pads. I use the same brush moistened with alcohol or acetone for cleaning the pads after soldering. This removes excess flux and debris, leaving a nice, shiny soldered pad.

Tools. In addition to the obvious — a soldering iron, wire cutters and the small pliers already discussed, several other small tools come in handy:
Tweezers are handy for positioning the pads when gluing to the board, in addition to holding small parts while soldering – particular surface mount components. *(Surface mount techniques will be presented in Part 2).*
Hemostats are another useful small tool for holding resistors or capacitors while soldering. They are locking, making it easy to hold the component with one hand while soldering with the other. Just ensure you don't over-squeeze the component to cause damage. Hemostats often allow a component to be held with a better grip than with tweezers.
Small screwdriver, flat-blade or phillips, is useful for holding down pads while the glue dries, pushing down ill-bent or stubborn component leads while soldering – even a lead bender to ensure smooth bends on component leads and internal wiring.
Q-tips are handy for cleaning or scrubbing around the pads after soldering, where a hobby brush may not often reach. Lightly moistened with alcohol or acetone, they are also useful for cleaning the components. When cut in two, the wooden shafts are also handy for holding down pads during gluing, or components while soldering.

Some of the small tools useful when building Manhattan style.

2. Some Practical Examples

THE ROCKMITE QRP TRANSCEIVER

Like hundreds of others QRPers, I built a ***Rockmite*** about two years ago when the kit was first introduced. The Rockmite QRP transceiver is a kit from Small Wonders Lab, furnished with a printed circuit board. I decided to highly modify mine, building it in a custom enclosure with a set of homebrew built–in paddles, something I always wanted to do. Additionally, it served as a test platform for a 5W Class-E PA circuit. The entire rig, including the paddles, was built of copper clad, except for the top cover, made from a scrap piece of perforated aluminum and painted black.

Fig. 11

The front panel, shown in **Figure 11**, was made from a piece of copper clad. Holes were drilled and the "square holes" for the power switch and paddles were filed to shape with a small jewelers file. After drilling, the copper clad was brushed with emory paper to rough up the copper a bit before applying a light coat of gray primer paint. The second coat, applied the following evening (this is a big hint for painting enclosures!) was a coat of light avocado green. The following evening, when fully dry, the light blue trim and boxes for the transmitter drive and receiver RF gain controls were painted by hand using a small brush. The legends were applied using rub-off

letters and sealed with a light coat of Krylon Protective Spray – available at many office supply or art stores. Clear enamel can also be used, but always test first on a scrap piece of material to ensure it doesn't "melt" the rub-off letters.

The front and rear panels were soldered to a copper clad "center" shelf, mounted about half the height of the two panels. This shelf serves to mount the Rockmite PCB and the paddles on the top (see **Figure 12**), and the transmitter components on the bottom.

The paddles are made entirely of pieces of copper clad, including the paddle pieces, as shown in the photograph of the top view. A 4-40 bolt and nut, with a spring from a BIC pen, formed the tension on the two paddles, while two other 4-40 machine screws serve as the dit and dah contactor and sets the spacing. It's not exactly a work of art, but they worked well, enough to have around 50 QSOs with this rig.

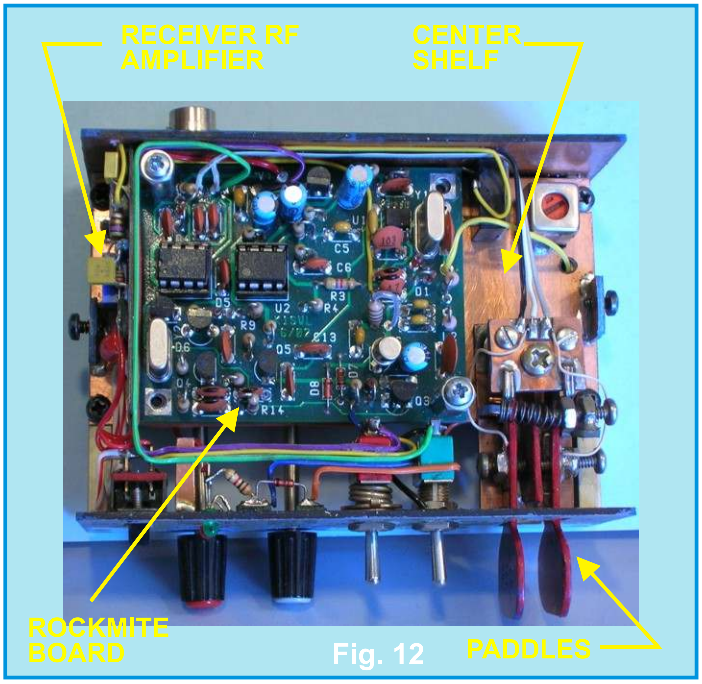


Fig. 12

Top view of the Rockmite. The Rockmite PCB and the homebrew paddles are mounted on the top portion of the center shelf.

The transmitter was built Manhattan style, with the pads glued directly to the bottom of the copper clad shelf. The IRF510 was mounted to an island cut-out of the copper clad by a Dremel tool. Since the IRF510 tab is the drain, this isolated the +12v on the drain tab from ground. Most of the interconnecting wiring was performed by using flat ribbon cable as shown in **Figures 13 and 14**.

The intent of this particular custom-made Rockmite kit is to show the flexibility of copper clad. It was easy to form the copper pieces into the desired front and rear panels, the center shelf, and even the paddle pieces. Granted, it took a little cutting and filing to form some of the pieces, but far easier than forming the same pieces from aluminum or metal stock. Plus, it can all be easily soldered together.

By applying a light primer coat before the final color of spray paint, copper clad makes an attractive and durable front panel as well.

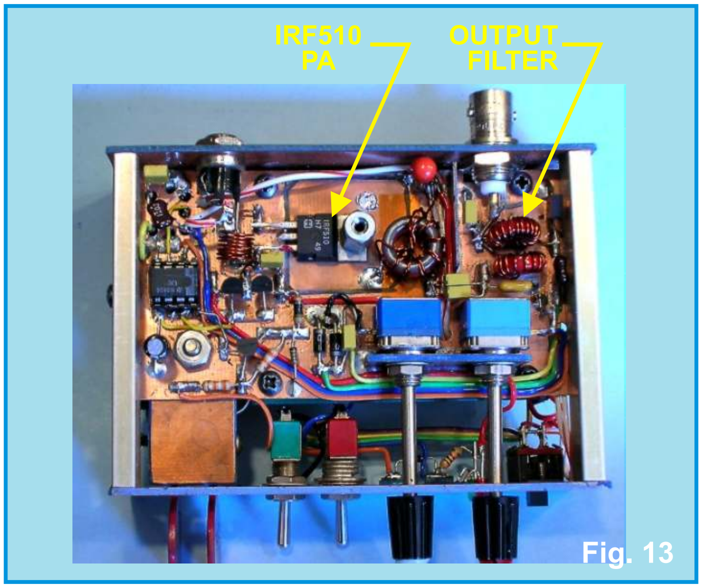


Fig. 13

Bottom view of the Rockmite, showing the home-brew transmitter section built Manhattan Style.

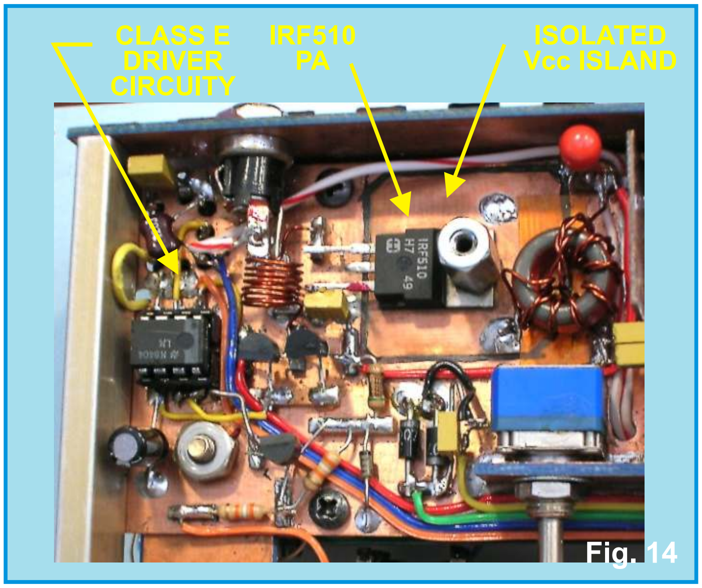


Fig. 14

A closer view of the transmitter section, showing the Manhattan style of construction.

MANHATTAN STYLE HOMEBREW TRANSCEIVER

I have built several QRP transceivers on different bands Manhattan style, mostly my own designs. In fact, that is one of the advantages I have found with Manhattan is how adaptable it is for a test platform. Changing components of different values to set proper biasing or gain is relatively easy, as is making circuit changes. Of course, too many circuit changes can get ugly as you try to fit things in you didn't originally plan on. But, it usually works fine. In the circuit shown here, I converted the RF amplifier from fixed gain to an AGC driven stage, moving around a few components from that originally planned.

The schematic (**Fig. 15**) is the "front end" portion of a 40M receiver I built, where T1 and T2 are Mouser 42IF124 IF cans. Q1 is a common base amplifier with the bias via R2 from the AGC line. C1 and C2 are the tuning capacitors to resonate T1 and T2 at the desired frequency (T1,T2 are 4.5uH nom. with no internal tuning capacitor). T1 is made resonant at the RF frequency and T2 at the IF frequency. Built Manhattan style, this RF amplifier and mixer scheme was fairly sensitive with a good noise figure.

The **Figure 16** photograph shows the "front end" portion of the receiver, based on the above schematic. With a little layout on paper first, the RF amplifier, receive mixer and 1st IF amplifier fits in an area about 1 x 2.5 inches. Interestingly, I also built a surface mount version of this same receiver, using the same IF transformers, and it took only about 1/4" less space! I used SOT-23 SMC 2N3904 transistors, which are about the same width as the TO-39 plastic versions. As a result, little space savings was noted – at least using this layout configuration.

The IF transformers are mounted on the main board in standard Manhattan style. See **Figure 17**. The only caution is to ensure the IF "can" is soldered to the main board with either the mounting tabs (if they reach) or with a piece of solid bus wire or a scrap resistor lead folded in two. Solder on two adjacent sides of the IF can for a firm mechanical connection.

Likewise, ground the desired pads(s) by soldering a wire or resistor lead to the main board for grounding. All transformer pins should go to a Manhattan pad to keep the IF transformer "level." Soldering the wire to ground the pad(s) to the main board also helps with the mechanical mounting without depending solely on the super glue. Otherwise, with a "stiff" IF can, you can twist the pads off the board while adjusting the center slug if not soldered directly to the board.

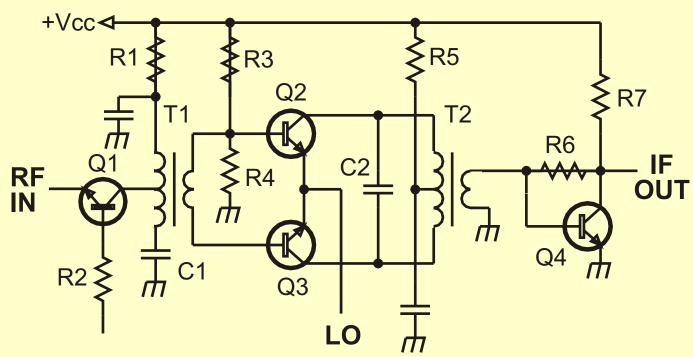


Fig. 15
Functional Schematic of the 40M "front–end"

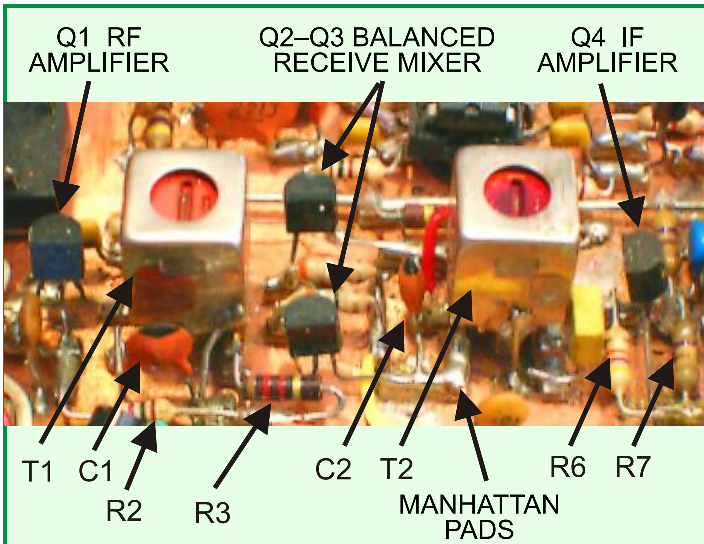
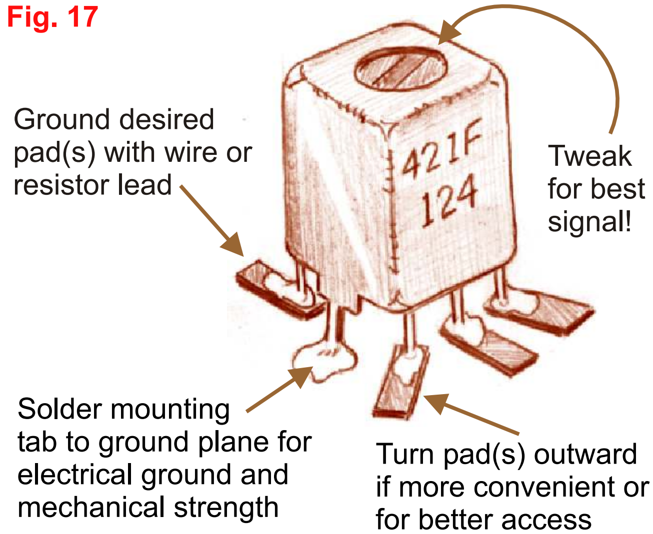


Fig. 16 – The "front-end" of a 40M QRP receiver built Manhattan style using IF "cans."

Fig. 17



Mounting IF Transformers Manhattan style

Following the 1st IF amplifier is the crystal ladder filter, as shown in **Figure 18**. Four of the crystals are for the IF filter, the one on the far left is actually the crystal for the transmit oscillator. The transistor in the upper left of the photograph is Q4, the 1st IF amplifier in **Figure 16** on the previous page. The wire soldered along the tops of the crystals serve two purposes: 1) to ground the cans to the main board, and 2) provide mechanical rigidity. Without this ground wire, I find myself constantly bending over the crystals while I'm building and poking around in the circuit.

Figure 19 shows in a bit closer detail how the crystals and shunt capacitors are mounted to the Manhattan pads.

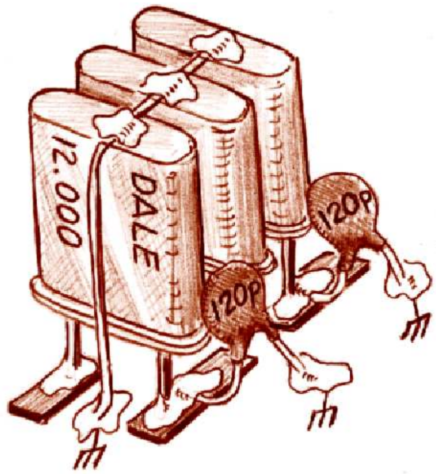


Figure 19

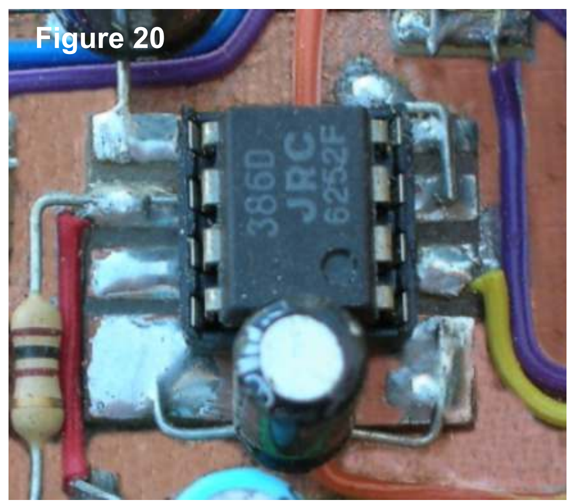
In mounting the crystals on standard Manhattan pads, the crytal leads need to be bent to fit. This is a case where cutting small strips of copper clad to length makes for a neater and more accessible assembly.

Figure 20 shows the LM386 audio output amplifier I.C.. This is such a simple, yet effective audio amplifier, it has become the benchmark amplifier in most QRP rigs.

I mount ICs either on individual Manhattan pads, or build a single pad as shown in the photo of **Figure 20**. This pad is made from a single piece of copper clad, cut into the pads as shown by sawing away the copper between the pins with a hack saw, coping saw, or a Dremel tool with a cutting disk. Then, obviously, another cut down the length of the IC to separate pins 1–4 from 5–8. Either method takes about the same amount of time, though the single Manhattan IC pad does look nicer, in my opinion.

If you make a rig out of copper clad, including the front and rear panels, don't forget the copper on these surfaces can be used as well. **Figure 21** shows one rig I built with the PA output filter mounted on the inside of the rear panel, next to the Antenna BNC connector. In this particular case, I etched away the unwanted copper with a Dremel tool, though Manhattan pads could just as easily be used. To the left of the filter (not shown) is the TO-220 PA transistor – also mounted on the inside rear panel. This allows the rear panel to serve as a large heat sink.

The IF Crystal Filter



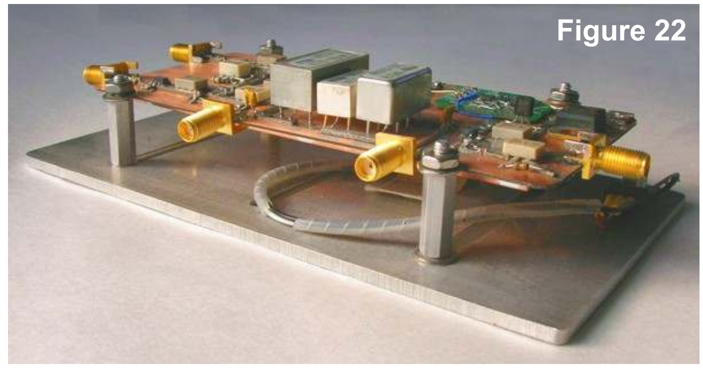
The LM386 Audio Output Amplifier IC

Figure 21

The PA Output Filter mountedon the inside of the rear panel saves space

A MANHATTAN BUILDING JIG

One of the difficulties I've experienced building small circuits is the copper clad board, weighing only a couple of ounces, moves all over the workbench surface as you work on it.



A building jig for holding down the circuit board for Manhattan style of construction.

Shown in the photograph is a Manhattan Building Jig (MBJ) I built for holding down a circuit board while it is being built and tested. In this case, I used a piece of aluminum and milled out several slots. In these slots ride the screw heads for the threaded standoffs. On the top of the standoffs, the washers and nuts secure the circuit board. Once attached, the screws on the bottom of the plate are tightened to hold everything rigidly in place. This allows different sizes of circuit boards to be mounted onto the jig. I have found this simple jig to really ease construction and testing. Particularly testing. Once you get a couple of cables and wires connected to the board, the weight of the cables alone will pull the board right off the bench! A jig with a little weight and larger footprint will keep this from happening.

On the far right hand side of the jig, under the circuit board and hardly noticeable, is the TO-220 voltage regulator used for the circuit. This places the voltage regulator close to the circuit and the base acts as a heat sink.

Of course, a jig of this nature could be built out of plywood or even a piece of 2x4. In this case, the board is held down to the jig with wood screws or other fastening scheme.

MANHATTAN – VHF STYLE

One of the "modules" I am responsible for at the VLA observatory is called the "4/P Converter." This converts our low-band receivers, being 74, 196 and 308–348 MHz, to an IF of about 1.1–1.4 GHz (L-band), then upconverted again to our 8–12 GHz X-band IF. In order to checkout this upconverter, I would need 4 signal generators, one for the three receivers and one for the 1024 MHz LO. I'd get killed by my co-workers for sucking up 4 of the lab signal generators everytime I needed to work on this converter! And, I've got 28 more of them to build over the next 3 years. So, I designed and built a test set that simulates the three receivers and the 1024 MHz LO. Additionally, it contains a sweep generator for "sweeping" the bandpass shape of the RF and IF filters on a spectrum analyzer.

Fig. 23 – A Manhattan-built Test Set used to simulate three VHF receivers and contains a 1024 MHz Local Oscillator

This was a fun "ham radio" project at work. It was built largely from copper clad and Manhattan style. Most of the parts were ordered from Mouser, All Electronics, Electronics Goldmine and MiniCircuits. The overall "4/P Band Test Set" is shown in **Figure 23**. The copper clad circuit assemblies are mounted vertically with the push-button switches and potentiometer controls protruding through the front panel. Details of two of these assemblies, the 74MHz oscillator and the 200-400MHz sweep oscillator, are shown on the next page. The meters indicate the output power level, normally set to –35dBm to simulate the receivers. While this is not a ham radio QRP project, it does contain many construction techniques that can be applied to any HF or VHF project. (Although, it *was*

built by a QRPer!). When I built this, I was a bit concerned at how the copper clad and Manhattan pads would behave at the VHF frequencies..It turns out, it works quite well. Wideband sweeps reveal only minor gain "suck-outs" between 600-1500 MHz. Rumors that Manhattan style should not be used above about 20MHz are thus unfounded, as proven with this project.

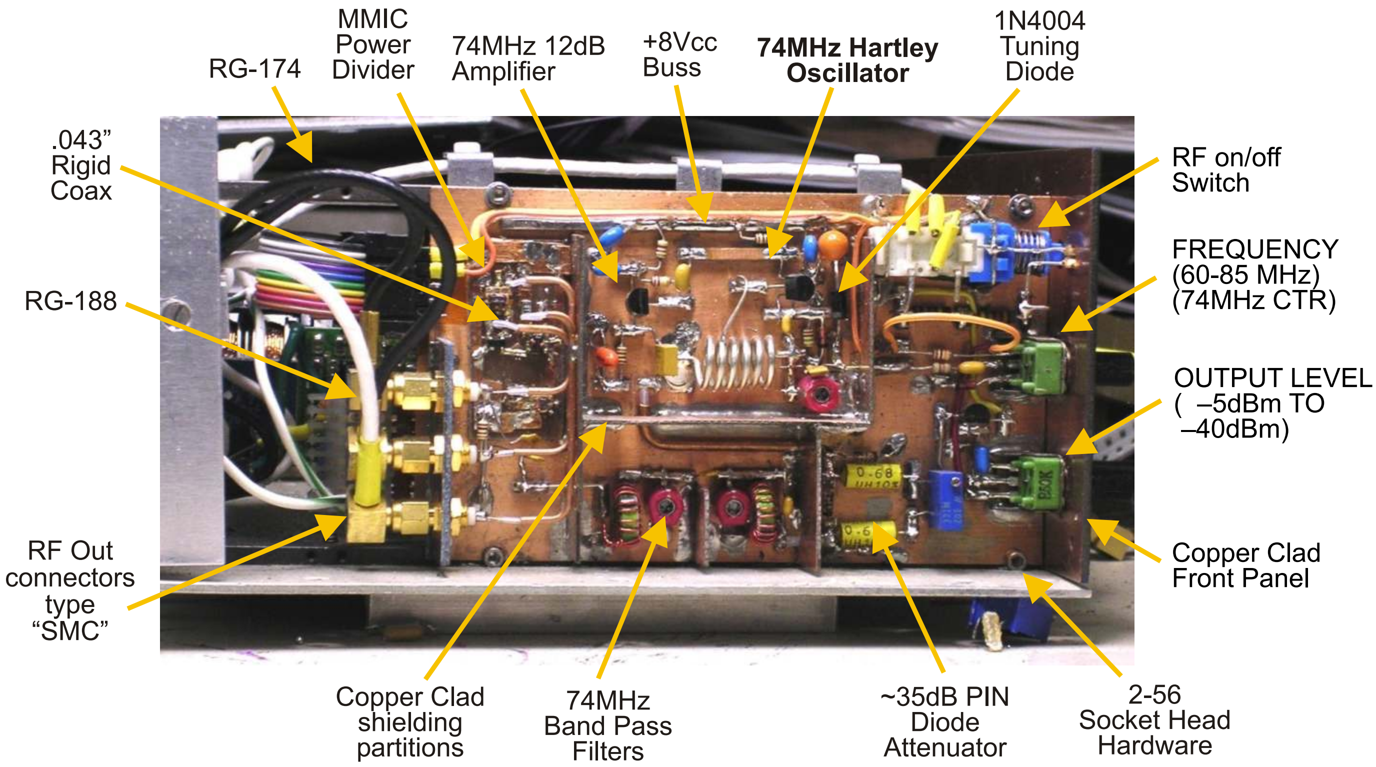


FIG. 24 — 74MHz OSCILLATOR (74MHz RECEIVER SIMULATOR)

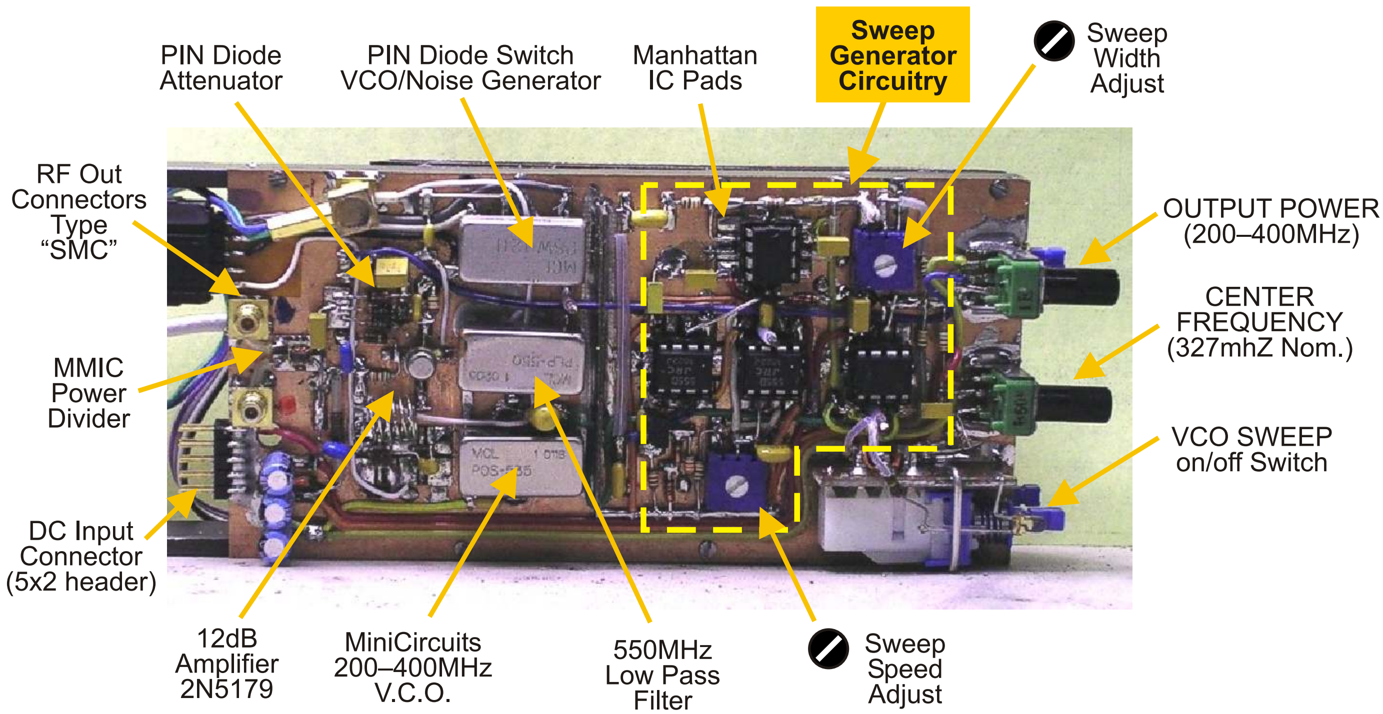


FIG. 25 — 200–400MHz SWEEP OSCILATOR (P-BAND RECEIVER SIMULATOR)

3. "Ugly" or Manhattan?

While the majority of this article focuses on Manhattan style of construction, it is not the only means to build a circuit. Since the dawn of radio, hams have built equipment "ugly style." Ugly has a charm of it's own.

Ugly began in the earliest days of vacuum tubes, where a circuit was built on a piece of smooth wood, mounting components between nails or screws – often just twisting the wires together, not soldered. Since a cheap piece of attractive wood in the early 1900s was a breadboard used by bakers, the term for this style of construction was called "breadboarding" – the genesis of the term still used today for building a one-of-a-kind circuit. Building on a breadboard could be anything from beautiful (**Fig. 26**)– to outright ugly.

Basically, building something ugly means "just throw it together" with little regard to appearance. Ugly also tends to imply building it cheaply as well, a common attribute of most hams – yesterday as well as today.

Today's breadboard tends to be a piece of copper clad. Component leads that are grounded are soldered to the copper clad surface as in Manhattan style. Everything else just gets soldered together, often with the components hanging in mid–air. The only concern is to make sure the component leads to do not touch ground or other things they shouldn't – often by bending or routing leads and wiring in a precarious manner. An example of this is the 7 MHz VFO built "ugly" as shown in the photograph of **Figure 27**.

A variation of the ugly circuit is called "dead bug." This technique is where the integrated circuits (the "bugs") are glued (or not) to a surface, face down, with the IC pins sticking up in the air for easy access. Wiring and components are soldered directly to these pins.

Regardless of the ugly method used, the circuits usually perform quite well. The biggest problem is stray capacitance from the often long component leads and wiring hanging in mid-air and in close proximity to each other. However, once the circuit is "tuned" to account for the stray capacitance, the circuit will work reliably – as long as you don't move or rearrange anything!

This becomes one of the biggest problem in ugly construction – duplicating the circuit. It often works fine for the first person building it, but when the circuit is built by someone else, results may vary. This is why early QRP publications seldom detailed how the circuit was built, as it was difficult to document to show exactly how the circuit was built.

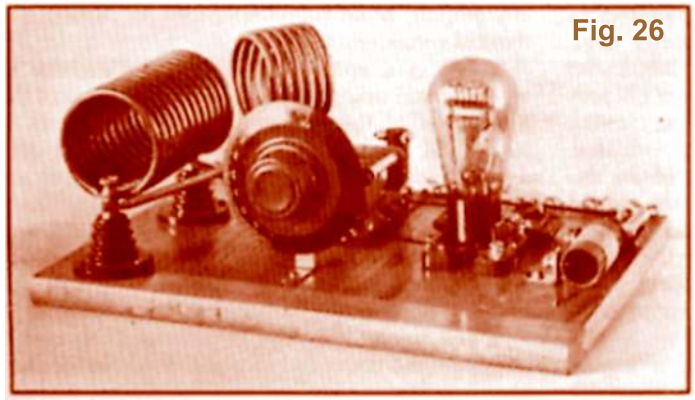


Fig. 26

From 1933 ARRL Radio Amateur's Handbook

Early ham equipment was often built on a standard 10 x 12.5 inch bread board, such as this 1930s "7000 kc low-power transmitter."

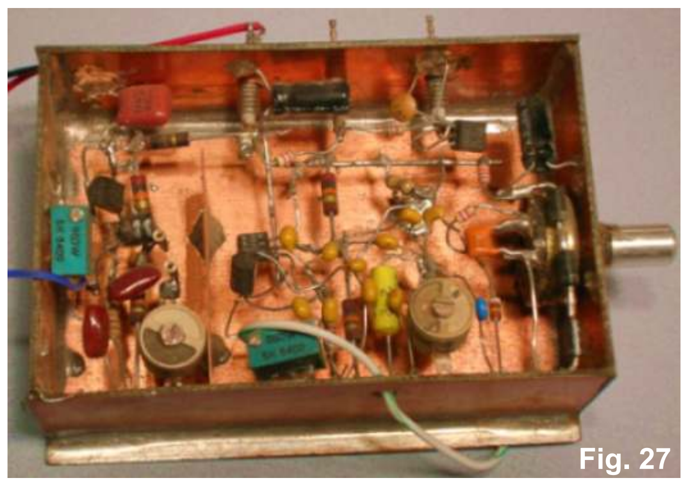


Fig. 27

The modern "breadboard" is often a piece of copper clad. This 7.0 MHz VFO was built "ugly style" in a copper clad "box."

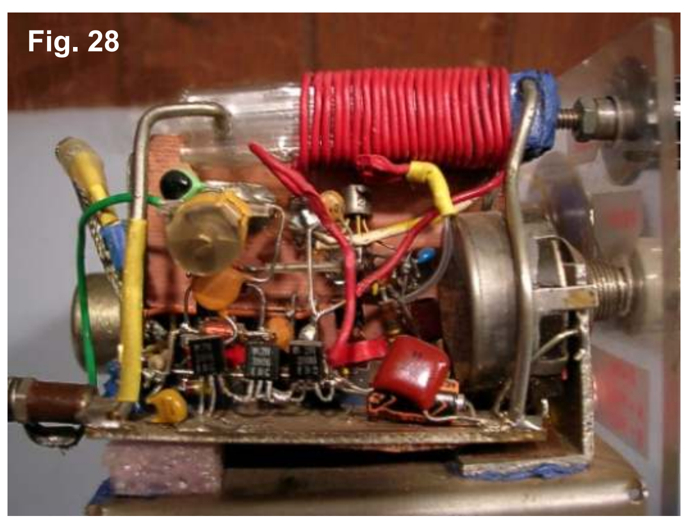


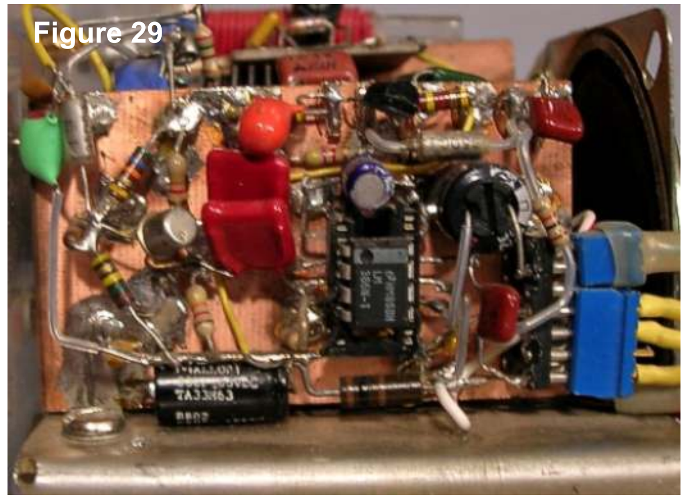
Fig. 28

A regenerative receiver built ugly style on a piece of copper clad. The coil is wound on an IC shipping tube.

In my opinion, this is the strongest advantage of Manhattan style for QRPers ... it is easy to document. Photographs or drawings illustrate exactly where each component goes and how it is built, ensuring consistency in construction amongst the various builders. This consistency also ensures the performance of the circuit will be about the same from unit-to-unit. This is why those people building Jim Kortge K8IQY's 2N2/40 were so satisfied with the results. Those who built it from the detailed drawings in the original QRPp article, the book, or on Jim's website, all ended up with a hot 40M transceiver with very similar performance to Jim's original. Had the 2N2/40s been built "ugly," this consistency in performance could not have been guaranteed. How would you document with any degree of accuracy the "ugly" circuit shown in **Figure 29**?

This is why Manhattan style has become so popular with QRP homebrewers. The designer can *clearly* illustrate *exactly* how to build the circuit to guarantee the expected results. The builder has *precise instructions* to follow and can build the circuit with the confidence it will work. This is true with the seasoned builder as well as the beginner. This is why Manhattan style has become the biggest boost to building a circuit "from scratch" by QRPers. Circuits designed and built Manhattan become excellent construction articles, since the step-by-step instructions lie mostly in the illustrations or photographs.

This is not to say building a circuit "ugly" style is inferior. As already mentioned, problems can occur in attempting to duplicate the circuit. However, for building a one-of-a-kind circuit, ugly can be a quick, cheap, dirty way to get it built and get it on the air. Over the years, I have had many QSOs with homebrew rigs built ugly. A couple were really ugly! The classic "Ugly Weekender" 40M receiver by Wes Hayward W7ZOI and Roger Hayward KA7EXM is a good example of a very nice performing rig built ugly style. It was featured in the 1992 Radio Amateur's Handbook and in the ARRL's book "QRP Power."



The AM detector and audio amplifier portion of a shortwave receiver built "ugly" style. The unused end-pins of the IC socket are soldered to the copper clad. The remaining socket pins are bent outward to make the connections.

There are few rules in building ugly. You simply "do your own thing" and get it working.

4. Conclusion

As most homebrewer's will tell you, there is nothing like the feeling of building a QRP rig and the thrill of having that first QSO with it. Whether you build ugly, a kit, or Manhattan style, QRPers will always be building their own equipment. This is why some of the QRP clubs and various vendors provide kits for building your own QRP transceiver. And, for those wishing to build a rig from scratch, this is why the QRP journals like the ***Homebrewer*** present as many construction articles as they can on the subject of homebrewing.

This article is intended for both the experienced builder and the new comer. If you've never built anything from scratch before, build a simple circuit using these techniques to "get your feet wet." AmQRP is committed to homebrewing. There will continue to be construction projects of different skill levels in future issues of the ***Homebrewer***.

In Part 2 **–** we'll continue with some of the construction practices employed in building circuits from scratch, including an emphasis on building with surface mount components, some various "hints and kinks," and a photo gallery of what others have built.

I am not a master builder of Manhattan. I never dreamed some of the stuff I've built would be featured in an article – or else I would have built them a little nicer! If you've built something from scratch, ugly or Manhattan, feel free to send me a photo or two to include in Part 2 to show what others have built, and how they built them. Likewise, if you have a construction hint or kink, send it to me and I'll gladly illustrate it for the next issue.

72, Paul Harden, NA5N
na5n@zianet.com

AWSH.ORG

stuff that i do and things that i make

new stuff

PUBLISHED SEPTEMBER 18, 2017

Last week I ran across a cryptic one sentence craigslist ad about ‘comm equipment’. There was no pictures or any other information, but I went ahead and emailed anyway. My email received a response with a phone number, which I called and found out that there was ‘a little bit of everything’. That didn’t tell me much, but I made plans to stop by on Saturday to see what he had.

The man I met up with was an 85 year old guy who had repaired radios professionally. He was basically clearing out most of the stuff that he still had laying around in his basement. I made him an offer for everything he had and he accepted.

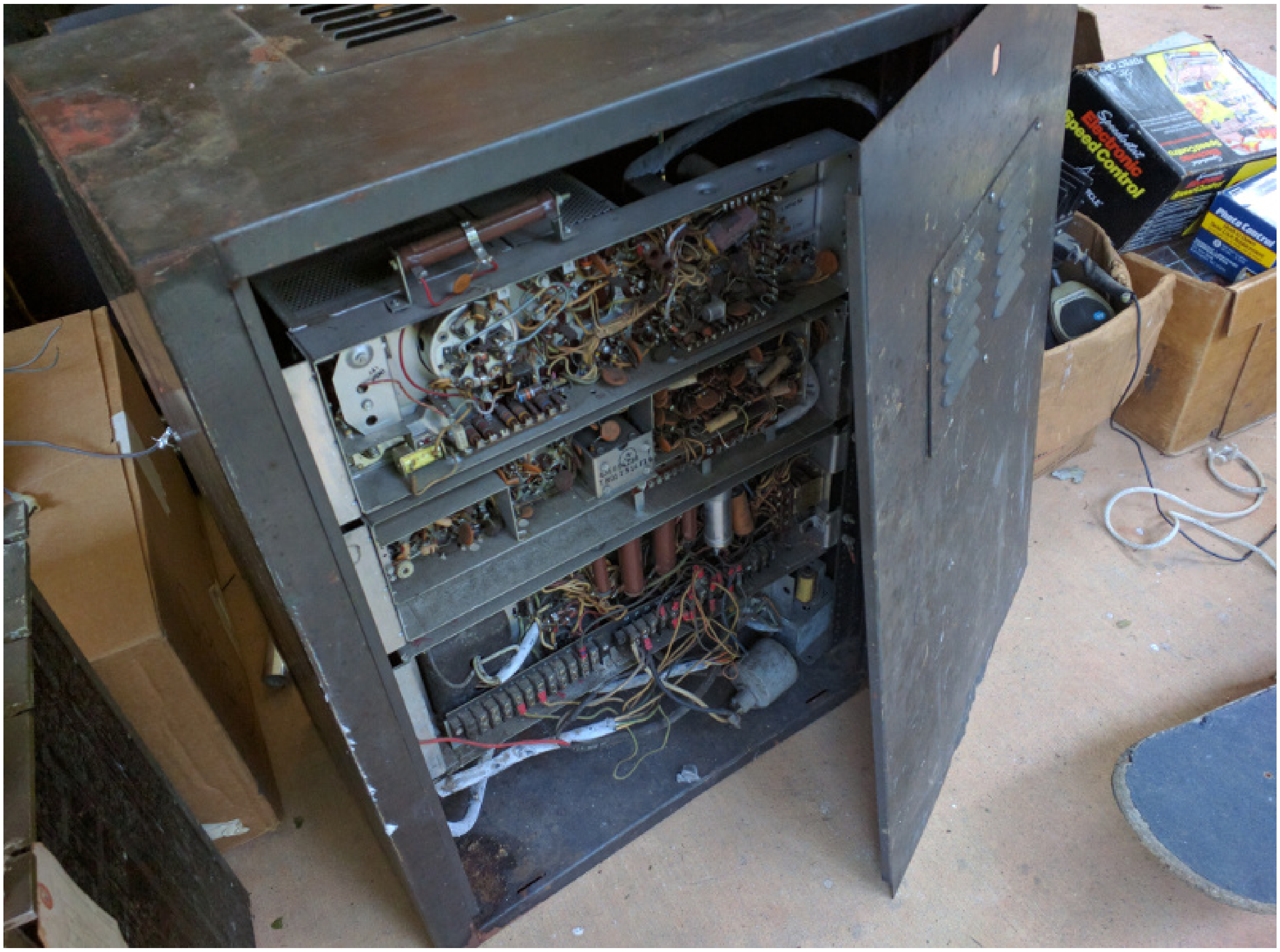
Here is most of it. I still had a bit left to unload when I took this picture.

There were boxes of old parts, tubes, transistors, crystals, and tons of other stuff. There were a few older radios, most of them old commercial motorola radios. There was a even a huge motorola repeater. There was quite a bit of test gear like frequency counters and signal generators, even an ancient oscilloscope. I got antenna tuners, dummy loads, morse keys, and all kinds of other cool stuff. I'll probably go through and work on bits and pieces individually, and I'll post more about things as I go through it all. I still don't know what all is in all the boxes. I still need to clean up everything and see what works and what doesn't, but for now, here are a few more pictures.


ICOM
2 METER TRANSCEIVER
IC-245
FM SSB CW
CARRYING CASE
11-7
3-11


HEWLETT PACKARD


PHONES
OFF
POWER
CHANNEL
FREQUENCY
MEGACYCLES
CHANNEL SELECTOR
REMOTE
MANUAL
LOCAL CONTROL
AUX CONTROL
ANTENNA

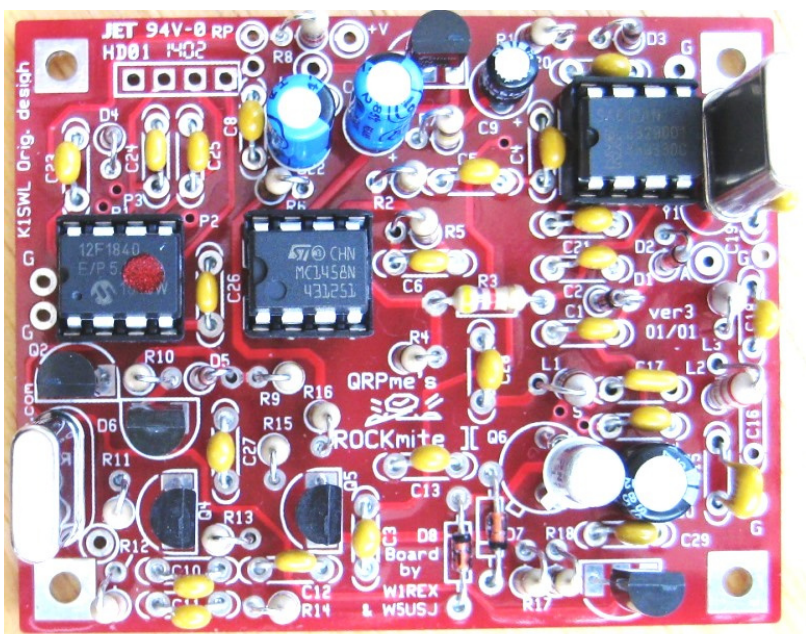

Electronic
Speed Control


ICOM
4MHz FM TRANSCEIVER
ICOM INCORPORATED
MADE IN JAPAN
ICOM
AC
BATTERY CHARGER
BC-30
117
ICOM INCORPORATED
ICOM
AC BATTERY CHARGER
BC-30

QRPme.com

Rockmite][Transceiver

By: Rex Harper, W1REX



Shown with Q6 socketed and without required heatsink

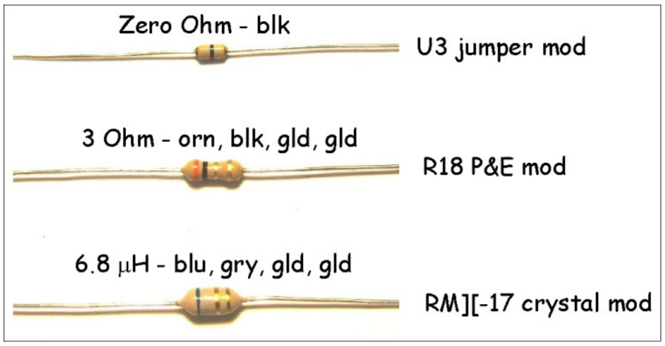
Rockmite][Builder's Guide v3 PCB

Rockmite][v3 Addendum

Changes, Updates, Revisions and Component Identification

Note: Completely read the Builders Guide and Builders Help manuals before beginning assembly of the kit!

Component Identification



The zero Ohm "resistor" is used to provide an insulated jumper for the U3 trace modification

The 3 Ohm resistor is used at component location R18 for the Power and Efficiency modification

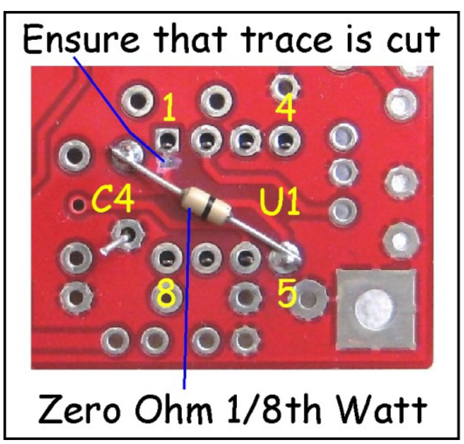
The 6.8 uH choke is used in series with an 18.096 MHz crystal for an RM][-17 modification. The purpose is to pull the crystal lower in frequency to a more active part of the 17 meter band.

2N3866
Markings or similar on the house-marked parts

U1-5 to C4/C5 Trace Mod (v3 PCB Only)

Note: Only 1 lead on the two components is soldered for this illustration.
This so the parts could be easily removed and the pads cleaned out.

Procedure:
Cut or ensure that the trace between U1-5 and U1-1 is cut.
Use care that no adjacent traces are cut.
Position the 0-Ohm jumper centered between U1-5 and the end pad of C4 at the C4/C5 junction.
A small piece of clear tape would help hold the jumper in place.



Solder (tack-solder) the jumper at the U1-5 end and trim the wire. Ensure that no shorts to other pins or pads have occured.

Connect the other end of the jumper to the C4 pad and trim the wire. Remove the tape if used.

Continue the assembly per the *Builders Guide*

The ***Rockmite*** *][v3 a Simple Transceiver*

List of Material (LoM)

Qty.	Ref. Designator	Component	Description
3	*C1, C2,C10, C11, C12*	*Band Specific*	*See page 2 Band Table*
5	*C15,C16, C17, C18, C19*	*Band*	
5	*C15,C16, C17, C18, C19*	*Band*	
3	*D3,D4,D5*	*Band*	
3	*L1, L2, L3*	*Band*	
2	*Y1, Y2*	*Band*	Crystals
4	C6,C24, C25, C26	100 pF disk or mono. cap	'101' or '101J'
5	C3, C13, C20, C21, C27	.01 uF disk cap	'103', ceramic
1	C4	.022 uF monolithic cap	'223', epoxy case
6	C5,C8,C14,C23,C28,C29	.1 uF monolithic	'104', epoxy case
1	C9	3.3 uF electrolytic cap	
2	C7,C22	47 uF electrolytic cap	
1	C30	47 uF electrolytic cap	low-profile case
4	D1,D2,D7,D8	1N4148 diode	Alt. 1N914
1	D9	1N5818	Polarity protection
1	D6	MVAM-109 varicap diode	
1	HS1	TO-18 or Alt TO-5	***see text***
1	LED Green	Power on Indicator	See modification sheet
2	3-pad MeSquares	Mod interconnection	
1	R0 Zero ohm Jumper	U1 trace fix jumper	Black band
1	R5 (Volume Pot)	1 Meg ohm linear	Optional Volume R5
1	R2 (Speed Pot)	50k ohm linear	See Keyer Manal
1	R18 (Power Mod)	3 ohm resistor	Brown-blk-gold-gold
2	R6,R18	10 ohm resistor	Brown-blk-blk-gold
3	R14,R16,R17	100 ohm resistor	Brown-blk-brn-gold
4	R1, R8, R13 R for LED	1K ohm resistor	Brown-blk-red-gold
2	R1, R8 for 9V operation	470 ohm – see text	Yel-violet-brn-gold
4	R2,R3,R9 (R1 for Speed)	4.7K ohm resistor	Ylw-violet-red-gold
1	R12	22K resistor	Red-red-org-gold
3	R11,R15 (R3 for Speed)	47K resistor	Ylw-violet-org-gold
2	R7,R10	100K resistor	Brown-blk-ylw-gold
2	R4,R5	1 M resistor	Brown-blk-green-gold
3	Q1,Q2,Q3	**2N7000 transistor**	(TO-92 package)
2	Q4,Q5	2N4401 transistor	(TO-92 package)
1	Q6	2N2222A TO-18 transistor	Alt. 2N3866 TO-5
1	U1	SA612/602AD IC	*in semiconductor bag*
1	U2	MC1458, LM1458 IC	8-pin DIP IC
1	U3 pre-programmed	**12F1840S keyer Chip**	8-pin DIP IC,
3	- -	8-pin IC socket	
1	SIP socket strip	10-pin strip	Crystal, Q6 sockets +1
1	- -	2-1/2" RG-174/U coax	
1	- -	Printed circuit board	W1REX Ver 3 PCB

Notes: Items in gray shading are in antistatic bag and those 2 items ***in bold (above) are static-sensitive***.

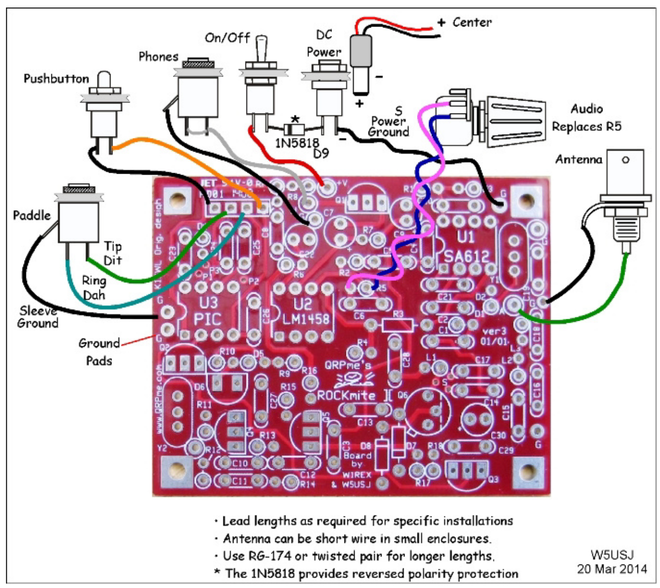
LoM Continued

Band Specific Components

Ref.	Band Table			
	80	40	30	20
C1	47pF C0G Mono (470)	47pF C0G Mono (470)	33pF C0G Mono (330)	47pF C0G Mono (470)
C2	33pF C0G Mono (330)	47pF C0G Mono (470)	33pF C0G Mono (330)	47pF C0G Mono (470)
C10, C11	68pF C0G Mono (680)	68pF C0G Mono (680)	47pF C0G Mono (470)	39pF C0G Mono (390)
C12	47pF C0G Mono (470)	47pF C0G Mono (470)	33pF C0G Mono (330)	39pF C0G Mono (390)
C15, C19	560pF C0G Mono (561)	470pF C0G Mono (471)	330pF C0G Mono (331)	220pF C0G Mono (221)
C16	Future Option	Future Option	Future Option	Future Option
C17	1200pF C0G Mono (122)	1000pF C0G Mono (102)	680pF C0G Mono (681)	470pF C0G Mono (471)
C18	240pF C0G Mono (241)	120pF C0G Mono (121)	82pF C0G Mono (820)	68pF C0G Mono (680)
D3	1N5231B 5.1V Zener	1N5231B 5.1V Zener	1N5231B 5.1V Zener	1N5233B 6 V Zener
D4	1N5231B 5.1V Zener	1N5231B 5.1V Zener	1N5231B 5.1V Zener	1N5230B 4.7 V Zener
D5	Not Used	1N5236B 7.5V Zener	1N5231B 5.1V Zener	1N5230B 4.7 V Zener
L1	15 uH RF Choke	10 uH Choke	6.8 uH RF Choke	4.7 uH RF Choke
L2, L3	2.2 uH RF Choke	1 uH Choke	0.68 uH RF Choke	0.47 uH RF Choke
Y1, Y2	Standard 3.560, 3.579545 MHz crystals	Standard 7.030, 7.040 MHz crystals or specify from list	Standard 10.106, 10.116 MHz crystals	Standard 14.050, 14.060 MHz crystals
The following items, from the original Rock-Mites, are listed here for reference only				
Series Filter (Ref.)	330 pF + 5.6 uH RFC	150 pF + 3.3 uH RFC	82 pF + 3.3 uH RFC	82 pF + 1.5 uH RFC

The series filter values were used in the original SWL RMs to meet -43dB FCC spurious suppression requirements.

Connection Hookup Components
BNC Antenna Jack
Coaxial Power Jack
Coaxial Power Plug
1N5818 Polarity Diode (D9)
Stereo Jacks, Paddle and Audio
Knob (optional)
Potentiometer, 1 meg (optional)
Push Button Switch
Power Wire
10-Conductor Ribbon – Hook up

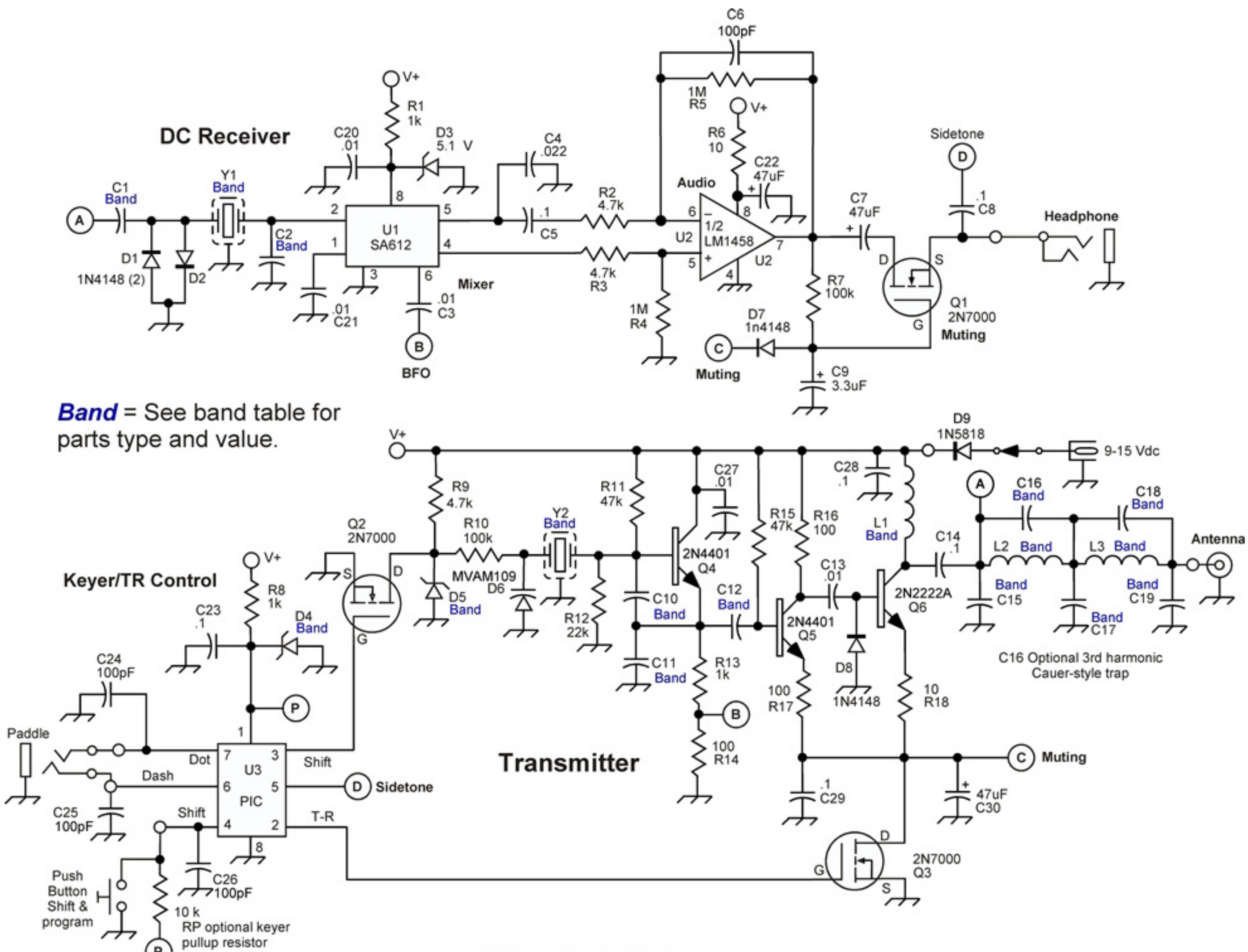


Basic wiring with optional volume control in place of R5.
See *supplement* pages for CR-425 enclosure assembly.

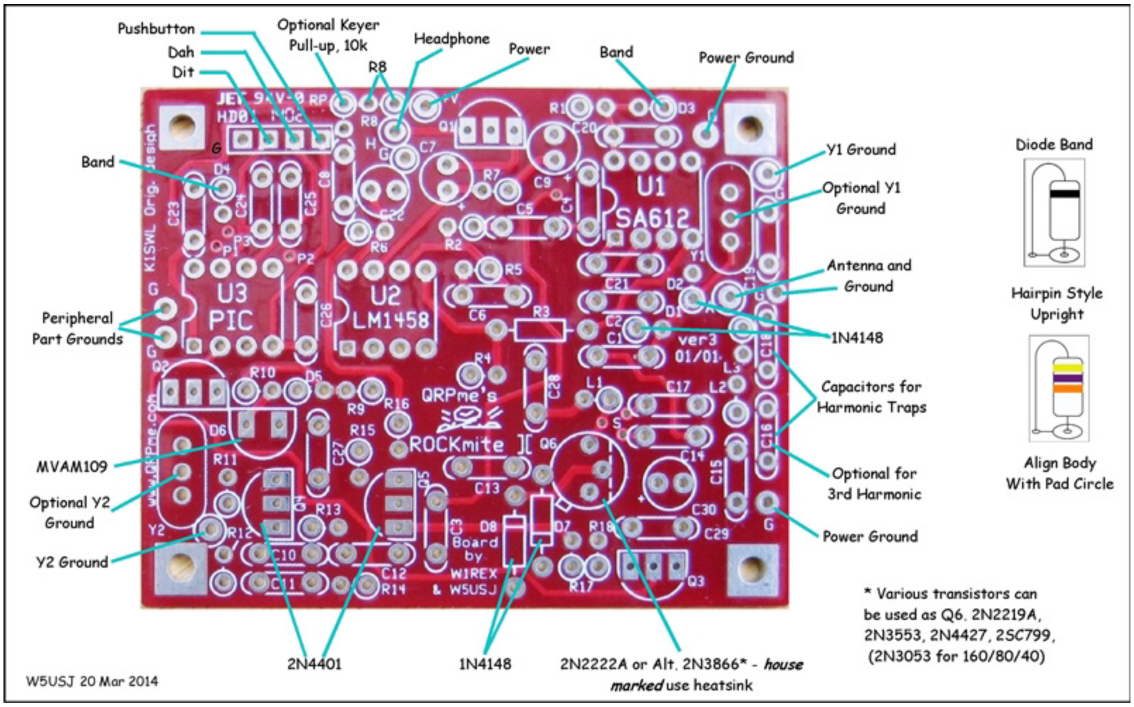
Crystal Grounding Option

For easy frequency changing use 3-pin SIP sockets at Y1 and Y2.
Add center ground lead to crystal as shown above. See ***RM][v3 Builders Help, pg 10***.
Note: SIP sockets will raise the height of the crystals and may limit use in mint tins and the MityBox. Leaving the leads long, the crystals can be bent over to fit the enclosures. Also, QRPme has some short, HC49S, crystal frequencies.

Schematic Drawing



QRPme Rock-Mite][W5USJ Drawing 3 Jan 2014



Assembly Sequence:

- **Download and print the *RM Builder's Help*** manual from the QRPme.com transceiver web pages
- **IC Sockets:** **(see the *RM][v3 Builders Help* *and* required** *U1-5 to C4/C5 Trace repair Mod.*
- **C30 Installation:** There are 3- 47 uF electrolytic capacitors in this kit**.** Install the short one at C30.
- **Q6 Installation:** Install the supplied heat sink HS1on the 2N2222A (or alt. 2N3866 house marked) before installation on the board. Q6 installation should be done late in the assembly to facilitate installation of shorter components nearby. Ensure that the heat sink does not touch the leads of any nearby components.
- **Resistors and diodes**: Most of the resistors and diodes and the RF chokes are mounted 'hairpin'-fashion. Diodes are orientation-critical- be sure to match the banded end of the diode to the wire bend as shown above at upper right, and follow the installation orientation shown on the pictorial above. Resistors are non-critical- their orientations shown above need not be strictly observed.
- **Crystals:**

If no future frequency change is intended install crystals as described below. Otherwise, refer to the grounding option, page 2.

Y1 and Y2 should be stood slightly (0.5 to 1mm) above the printed-circuit board to prevent shorts from case to PC-board traces. Install short lengths of leftover resistor lead from the bottom end of both crystal cases to the nearest ground point. [The crystal cases are tinned and will accept solder readily- use a minimum of heat.] *You'll find it easiest to stand the wire lead up in its mounting hole and solder it first, then cut the wire short, bend it over to the crystal case and solder that end.*

Spare ground pads are provided next to Y1 and Y2. Lay the board down on a flat surface and stand a leftover component lead upright in each hole. Solder on the top side of the board and trim the lead length to 4-5 mm. Bend this 'flying' lead over to the crystal cans and solder to the crystal. Use minimum heat, hot iron, quick solder connection. Get it done quickly.

- Remaining parts may be installed without regard to sequence. It may be helpful to note the tight clusters of parts and install those first. Install ICs in the sockets as shown above- see the supplement for orientation info.

Rockmite][operation:

The Rockmite][, using parallel resonant crystals, operates on approximately ***0.5 to 1.5 kHz lower*** than the crystal's marked frequency. The microcontroller provides a 'shift' signal to the local oscillator. This signal changes state upon key-down and key-up and provides approximately 700 Hz frequency shift (FSK). For series resonant crystals, the opposite is true.

The Rockmite][includes a supplied Iambic Keyer, U3. Refer to the Picokeyer-RM][manual for detailed operating instructions

If either the Dot or Dash inputs is grounded upon power-up, the keyer function is bypassed and the other input accepts a straight-key or external keyer. This is achieved automatically by the use of a 3-conductor jack and 2-conductor (monaural) plug. Alternately, refer to the Straight Key Mode in the keyer ma nual.

Third Party Keyers:
RMK from Jackson Harbor http://wb9kzy.com/rmk.htm A keyer chip with basic features and functions
PicoKeyerRM from HamGadgets
http://www.hamgadgets.com/index.php?main_page=product_info&cPath=21&products_id=48
A full-featured keyer chip with extended features and functions.
Visit the respective website for a copy of the manual describing the features and functions of these two keyers.

'Pushbutton' Input

- A brief (<250 ms) closure to ground on the 'switch' input reverses the offset to provide a second operating frequency. **Frequency selection**: When you wish to work another station, use this function to select the higher of the two pitches on a received signal. Note that the pitch at the other setting is a measure of how close to zero-beat you are; ideally it would be just a low-frequency 'thump'. If the two selections yield 'high' and 'higher' you probably won't be able to work the other station.

- For the original SWL Rock-Mite keyer chip only (12C508A), a longer (>250 ms) closure to ground on the 'switch' input puts the keyer in a speed-adjustment mode. The Rockmite][outputs a Morse code "S" to acknowledge entry into this mode. Tapping (or holding) the dot paddle speeds up the keyer; the same operations on the dash paddle slow it down. The default (power-up) speed is approximately 16 WPM and the upper and lower limits are ~40 WPM/5WPM If no dot/dash inputs are received over an interval of ~1.5 seconds, the Rockmite][outputs a lower-frequency tone and reverts to normal operation. *The Morse "S" and subsequent tones are not transmitted on the air.*

Design modifications may be found in the Rockmite][Builder's Help and on-line at the URLs below.

On-Line Resources:

Modifications and tips: http://www.qsl.net/n0rc/rm/
Yahoo Rockmite Group:
http://groups.yahoo.com/neo/groups/Rock-Mite_Group/ Approval with Valid Call and Real Name only.

Missing Parts : Rex Harper W1REX tunacankits@gmail.com

This document is based on the original Rock-Mite Instructions by Dave Benson, K1SWL.
Edited by: Chuck Carpenter, W5USJ

* * *

The MBDC

A Multi-Band, Direct Conversion Transceiver

Steven Weber, KD1JV steve.kd1jv@gmail.com

Distributed by Pacific Antenna, www.qrpkits.com

Specifications:

Rx current:

80 M : 70 ma, 160 M : 100 ma

Sensitivity: ~ -90 dBm (5 uV)

Three audio bandwidth settings

Transmitter:

80 M : 5.5W at 13.8V, 620 ma

160 M : 5.5W at 13.8V, 810 ma

Features:

2X16 LCD display

Internal speaker

Auxiliary receiver antenna input

100 kHz to 21.5 MHz General coverage receiver tuning

20 frequency memories

Iambic B mode keyer with message memories and beacon mode.

The Multi-band, Direct Conversion transceiver (MBDC) is designed primarily for operation on the 160 and 80 meter ham bands. The wide tuning range of the DDS VFO also allows for general coverage tuning of 100 kHz to 21.5 MHz and the Direct Conversion receiver allows for the reception of all modes.

Three receiver audio bandwidths are available and are selected with a push button on the front panel. AGC and independent volume control prevents ear shattering volume levels with very strong stations.

160 and 80 meters was chosen for the stock operating bands for two reasons. One, there are not many kits available for these bands. Two, the Direct Conversion receiver is best used on bands which are generally not all that busy or crowed. Operating a DC receiver on the busy 40 and 20 bands can be very frustrating!

For use outside the 160 and 80 meter ham bands a separate auxiliary receiver antenna input is used. This by-passes the transmitter low pass filters and a 1.7 MHz high pass filter which would limit reception to the two ham bands. The auxiliary antenna input can also be used on the selected ham band if desired, as it can be desirable to use a dedicated receiver antenna on the top bands to reduce noise pick up.

The auxiliary receiver antenna input goes directly to the mixer without any filtering or tuning as this would seriously complicate the design and expense for general coverage tuning. Also, the receiver is not overly sensitive as there is no need for it on the Top bands. Too much sensitivity would just raise the noise level and degrade the S/N ratio. Note that the receiver is also sensitive to stations at the second harmonic of the LO.

Therefore, adding some sort of pre-selector and possibly a pre-amp would be helpful when used as a general coverage receiver, which is another reason for including the auxiliary receiver antenna input.

An open Drain MUTE output is available for control of a pre-selector or for the control of an external linear amplifier.

Because of the wide frequency tuning available with the DDS VFO, it would be a shame not to allow full use of this capacity. Therefore, it is possible to program the MBDC rig to operate on bands other then 160 and 80 meters. However, it is not a good idea to use the transmitter above 17 meters due to possible stability problems and the fact the transmitter output filter becomes very touchy above 18 MHz.

Unless programmed differently, the transmitter is only enabled within the limits of the 80 and 160 meter ham bands. If you tune out side the currently selected ham band, the transmitter will be disabled and this is indicated by a [*] in the upper left of the display.

Limits can be programmed so that the transmitter is enabled between two frequencies of your choice. These are typically the high and low ends of the given ham band. However, if use as a signal generator is desired they could be set to the tuning range of the DDS VFO, 100 kHz to 21.5 MHz. Programmable limits also allows setting up the rig to use on the LOWfer bands.

Operation:

Controls:

Rotary encoder with push button switch on shaft and three push buttons.

Push button #1 : MENU button

Push button #2 : Receiver bandwidth selection.

Push button #3 : RIT on/off or Change Bands

Encoder push button : change tuning rate.

Most of the switches can have more then one function.

Band selection:

The MBDC powers up on the 80 meter band, which is also known as “Band A”.
To toggle between bands, press and hold closed the RIT switch for one (1) second.

Tuning rate:

The current tuning rate is indicated by a line under the decade which is active. Tuning rates of 1 Hz to 100 kHz can be selected. Note that the 10 kHz decade actually tunes at a 5 kHz rate, which is useful for tuning SWBC stations and AM broadcast stations.

To change the tuning rate:

- Push in the tuning knob.
- The cursor indicating the active decade will start to blink.
- Use the encoder to move the cursor to the desired tuning decade
- Push the tuning knob again to exit.

RIT:

RIT (Receiver Incremental Tuning) is imperative for a DC transceiver. If you wish to communicate with someone your transmit frequency must match theirs, but to hear them you must tune away from their transmit frequency. This is done using RIT.

The procedure is to first “zero beat” the other stations signal with RIT off. You want a zero Hertz zero beat and this is best detected using the non-filtered “wide band” audio filter setting.

Once you can no longer hear a beat note from the other station, you can turn on RIT and tune about 600 Hz above or below the station to get a beat note you can copy. You can also select one or both of the audio filters to remove QRM and other wide band noise to make the signal easier to copy. The audio band pass filters have a center frequency of about 600 Hz.

This procedure isn't very quick to perform and by the time your done someone else may have answered their CQ or they have given up calling. It is often more productive for you to call CQ and hope stations come back to you.

RIT operation:

- RIT is turned on and off by momentarily pushing the RIT switch.
- NOTE: While RIT is enabled, code speed setting is the only Menu function which can be selected. You must exit RIT to enable other menu switch functions.
- The RIT tuning rate will automatically be set to the 10 Hz rate and restored to the original tuning rate when RIT is exited. The tuning rate can be changed manually while in RIT mode if desired.

While in RIT mode, the delta or difference between your new receive frequency and the transmit frequency is show on the display below the transmit (“base”) frequency, as a + or - frequency. The displayed delta can be up to +/- 99.999 kHz, although there is no actual limit to how far you can tune away from the base frequency, so be careful of this.

Receiver band width selection:

Momentarily pushing the Bandwidth switch will toggle through the three selections, the selected mode will be shown on the LCD to the right on the top line:

1. Wide band (WB)

2. Narrow filter 1 (F1)
3. Narrow filter 2 (F2)

Wide band results in no filtering for AM and SSB reception.

Narrow filter 1 is a band pass filter centered on 600 Hz. It is wide enough that it can help improve reception of AM and SSB signals with noisy band conditions.

Narrow Filter 2 is an identical band pass filter in cascade with the first. This significantly narrows the pass band for CW reception.

Each of the band pass filters has gain which helps in reception of weak CW signals in addition to removing noise and near-by stations.

Note that AGC is derived before the band pass filters. Otherwise an oscillation condition occurs if the signal first passes through the filters, due to the propagation delay. This means any strong signal in the vicinity will pump the AGC, even if its not the signal you want to copy.

MENU:

The menu switch is a timed switch which cycles through the selections as it is held closed. When the desired function shows up on the display, release the switch to activate that function. Functions are selected in the following order:

1. Code speed / activate message memory selection for transmit
2. Programmable Frequency memories
3. Keyer memories
4. Enable AUX Rx antenna all the time.

In general, pushing the MENU button again will escape the function which was just selected and pushing the Tuning knob button is used as the “ENTER” button to load or store data.

Code speed:

Momentarily push and release (tap) of Menu switch (on less than 1 second)

- The current code speed will be displayed. Code speed range is 5 to 40 wpm.
- Use the paddle or tuning encoder to increment or decrement the code speed.
- After about 2 seconds of idle, this mode will time out and return to normal operation.
- The selected code speed will be stored in EEPROM and will be become the new default power on code speed.

- The encoder allows changing the code speed while in Straight Key mode so that the speed at which a message can be sent at can be changed.

Frequency memories:

User memories:

Display [F MEM] while Menu switch depressed, then [Mxx   0.100.000] when released. Where xx is the memory location and the number following the frequency currently in that location. 100,000 kHz is loaded if the location has yet to be used, as that is the minimum operating frequency.

1. Use the rotate the tuning knob to select one of 20 locations, 0 to 19. Locations 20 to 27 are special purpose memories and are not to be used for general memories.
2. Load the frequency as shown on the bottom line of the display by pushing the RIT switch.
3. Store the current operating frequency as shown on the top line of the display into memory by pushing the FILTER switch.
4. Escape by pushing the MENU switch.

Special purpose memory locations 20 to 27:

Location 20 and 21 are used to store a power up frequency other then the preprogrammed default frequency.

M20 = Band A power on frequency (nominally in 80 meter band)
M21 = Band B power on frequency (nominally in 160 meter band)

NOTE: the new power on frequencies don't have to be within the associated band, but if they fall outside the band limits, the transmitter will be disabled.

Locations 22 to 27 are used to program new power on operating frequencies and tuning limits for each band.

For Band A:
M22 = Lower transmit frequency limit
M23 = Power on frequency
M24 = Upper transmit frequency limit

For Band B:
M25 = Lower transmit frequency limit
M26 = Power on frequency
M27 = Upper transmit frequency limit.

Keyer Memory:

Display [EMEM]

This mode allows entering Morse messages via the paddle. There are two message locations of up to 63 characters in length (word spaces are characters). Letters, numbers and most available Morse punctuation and special ASCII characters are decoded and displayed on the top line of the display. This helps ensure proper entry of the messages. A back space function is available to erase mistakes or eliminate word spaces which are automatically inserted.

- Hold the MENU switch closed for at least 3 seconds.
- The display will change when this mode is activated. The frequency reading is cleared. Characters you key in will appear here. The characters "X", "BS" and "R" are written on the bottom line to remind you of the functions of the push buttons.
- "X" = eXit = Menu switch, "BS" = Back Space = Filter BW switch. "R" = review = RIT switch.

- When you start to enter a message, the Morse characters are decoded and displayed on the top line. When the line fills up the characters will start to scrawl.
- If you enter something which does not decode to a valid Morse ASCII character a "!" will be displayed. Although "!" is a valid Morse character, nobody would know what it is if you sent it.
- When a word space is inserted, a blank will be written to the display, moving the cursor over a space.

- Tap the MENU switch to exit this mode at any time prior to storing a message.
- Back space to erase mistakes by pushing the filter BW switch.
- Push the encoder PB switch to review message.

- If you try to exceed 63 characters, [FULL] will appear on the display. If this happens, you have three options.
  1. Store the message as is.
  2. Back space to remove some letters or words. Note, the "full" message will not be erased, even though the memory is no longer full.
  3. Exit the memory entry mode and start again.

When you've finished keying in your message, push the RIT switch. The message will play so you can decide if you like the way it sounds or not before actually storing it. If you want to start over, push the MENU button. Other wise, store the message in one of the two memory locations.

- Tap the Dot or Dash paddle to store the message in location 1 (dit) or location 2 (dah)
- A message location can be cleared by pushing the encoder switch before any characters have been entered and then the dot or dash paddle for the location you want to clear.

Sending messages:

- Tap the Menu button, then with in ½ second,
- Tap the Dot paddle for memory location 1
- Tap the Dash paddle for memory location 2
- Once a message has started sending, it can be terminated by closing the DOT paddle. If a character is being sent you must hold the paddle closed until it finishes sending.
- If in Straight key mode, only message memory 1 can be used, as that is activated by the DOT input also used by the Straight key.

Beacon mode:

Either message memory can be set to repeat automatically, this is called "beacon mode". Beacon mode can be terminated by

closing the DOT paddle in between the sending of characters. Using the paddle, Dot or Dash, during the pause time will terminate the beacon mode and go directly to keying the transmitter.

The pause between message repeats can be set to between 1 and 6 seconds via the tuning encoder. The initial time is 1 second. The up/down tuning bit is tested only during the pause time. Therefore, using the tuning encoder while the message is being keyed will change the delay by 1 second when the pause starts.

To start the beacon mode:

- Start one of the two messages sending {tap menu, then dash or dit}
- Push the Menu button. Switch is detected between characters.
- [BEACON 1s] will be written on the bottom line of the display, where 1s is the pause time.

Straight key mode:

- While power is OFF, plug a monaural plug into the paddle jack, then turn on power. Straight key mode is activated if the DASH input is grounded at power up.
- While in straight key mode, keyer memory entry mode is disabled, since it requires a paddle for use.
- Keyer Message 1 can be activated with the straight key if a message has been previously stored. Code speed can be changed with the tuning encoder.

Enable Rx Antenna all the time:

Normally, the Auxiliary Receiver antenna input is only selected if you tune outside the limits of the currently loaded ham band. However, if you wish to use a receiver antenna separate from the transmitter antenna, this is possible to do using this selection.

Display [Rx ANT OFF]

- Tap <FILTER> to toggle the Rx antenna on or off. A character which sort of looks like an antenna symbol will appear on the upper left of the display when the Rx antenna is active.
- Tap <MENU> to store and exit.

Auxiliary MUTE output:

The MUTE terminal on the board is an open drain output which is active LOW while receiving. The Mute output goes high just before the transmitter is keyed and goes back low after a word space time at the current code speed when using the keyer or about 5 ms when using straight key after the transmitter is un-keyed.

This output can be used to control an external linear amplifier. However, since the output is HIGH (open) during transmit, it can not be used directly with the PTT input of most amplifiers, since the amplifier PTT input typically needs to go low (grounded). In this case, the MUTE output needs to be inverted, which can be simply done by adding a pull up resistor and either a NPN Or N channel MOSFET between the MUTE output and the PTT input. These parts can be added right at the RCA output jack.

Frequency calibration:

The output frequency should match the display close enough that no calibration is really required. However, if desired this is possible to do. Calibration is done at 10 MHz, so it is possible to “zero beat” WWV. The best way to do that is to run the audio from the receiver into your PC running a PSK program and use that to measure the frequency of the WWV tones.

- Turn power on with the MENU switch depressed.
- The display will show the reference frequency. Tuning step is set to 1 Hz. This can be changed of desired, but is not recommended.
- Use the tuning encoder to set the output frequency to exactly 10.000,000 MHz. *Increasing* the reference frequency will *lower* the DDS output frequency.
- Press the MENU button to store and exit.

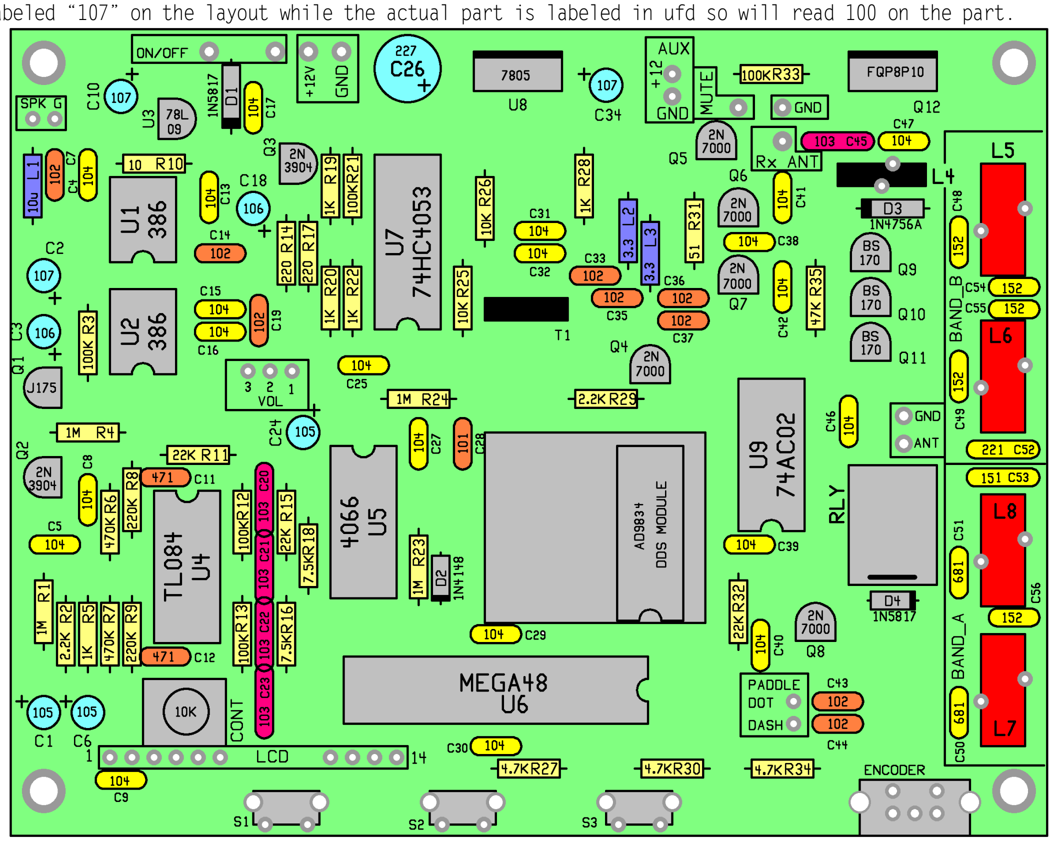
Parts list

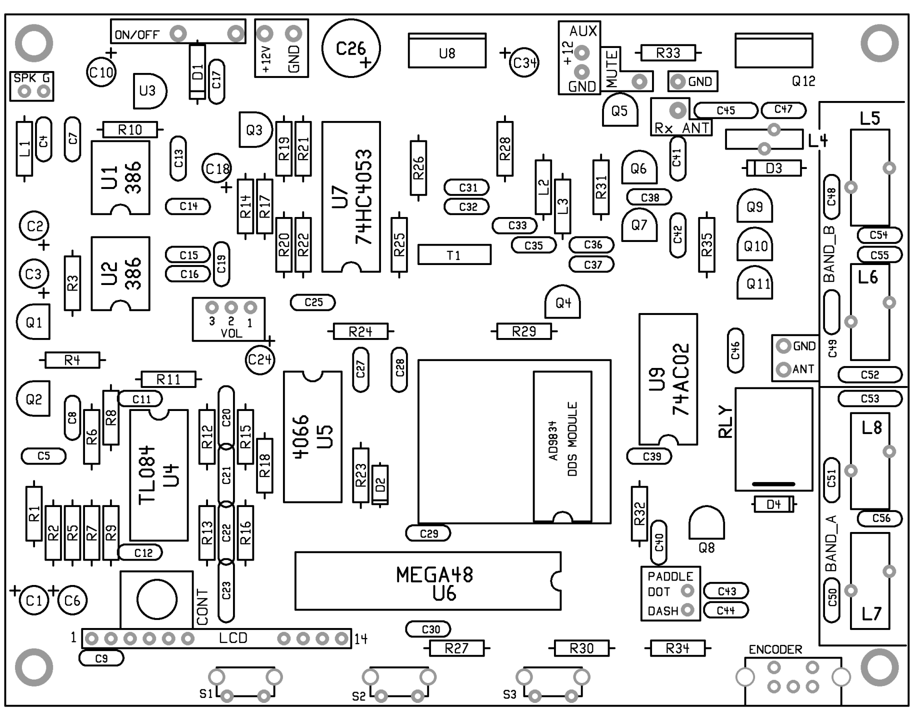
	QTY	VALUE	Description		QTY	VALUE	Description
	2	LM386	Audio amplifier		21	0.1 ufd (104)	MMLC
	1	TL084CN	Quad low noise op amp		3	1 ufd / 50V	electrolytic
	1	LM78L09	9V 100 ma regulator		2	10 ufd / 16V	electrolytic
	1	4066BE	Quad analog switch		3	100 ufd /16V	electrolytic
	1	ATMEGA48PU	Microprocessor		1	220 ufd /16V	electrolytic
	1	74HC4053E	Analog switch				
	1	LM7805ACT	5V 1A regulator		2	8 PIN SOCKET	
	1	74AC02N (or 74HC02)	Quad NAND gate		3	14 PIN SOCKET	
	1	J175	P-channel jfet		2	16 PIN SOCKET	
	2	2N3904	NPN		1	28 PIN SOCKET	
	3	2N7000	MOSFET		1	8 PIN SIP	Header pins
	1	FQP8P10	Power MOSFET		4	T50-2	Red toroid
	3	BS170	MOSFET		2	FT37-43	Black toroid
	2	1N5817	Shotky diode				
	1	1N4756A	47V 1W zener		1	Mechanical encoder	RT angle, pc mount
	2	1N4148			3	RT ANG TACT SW	PB switch
	2	3.3 uHy	RFC - GRN/GRN/GLD/GLD				
	1	10 uHY	RFC - brn/blk/blk/gld		1	50 K W/ON-OFF	VOLUME
	1	10 ohms	brn/blk.blk/gld		2	BCD JACK	
	1	51 ohms	grn/brn/blk/gld		2	3.5mm stereo	Phone jack
	2	220 ohms	red/red/brn/gld		1	2.1 mm POWER	Jack
	5	1 K	brn/blk/red/gld				
	2	2.2 K	red/red/red/gld				
	3	4.7 K	Yel/ violet/red/gld				
	2	7.5 K	Violet/grn/red/gld			#28 magnet wire	
	2	10 K	brn/blk/org/gld		3”	20 COND RIBBION	
	3	22 K	red/red/org/gld		1	CIRCUIT BOARD	
	1	47 K	yel/violet/org/gld				
	5	100 K	brn/blk/yel/gld				
	2	220 K	red/red/yel/gld			#24 or 22	Hook up wire
	2	470 k	YEL/VIO/YEL/GLD				
	3	1 MEG	brn/blk/grn/gld				
	1	10 K	trimmer		8	4-40 1/4”	Machine screw
	1	100 pfd (101)	disk				
	1	150 pfd (151)	C0G		1	Small knob	
	1	220 pfd (221)	C0G		1	Large knob	
	2	680 pfd (681)	C0G		1	Cabinet	
	5	1500 pfd (152)	C0G		1	2X16 LCD display	
	2	470 pfd (471)	Disk		1	AD9834	DDS Module
	9	1000 pfd (102)	Disk				
	5	0.01 ufd (103)	FILM				

Board layout:

Print this page for reference as you build.

Note:
Capacitor values are shown with a 3 digit convention, the third digit being the zero multiplier and with pfd as the base.
100 ufd is labeled “107” on the layout while the actual part is labeled in ufd so will read 100 on the part.



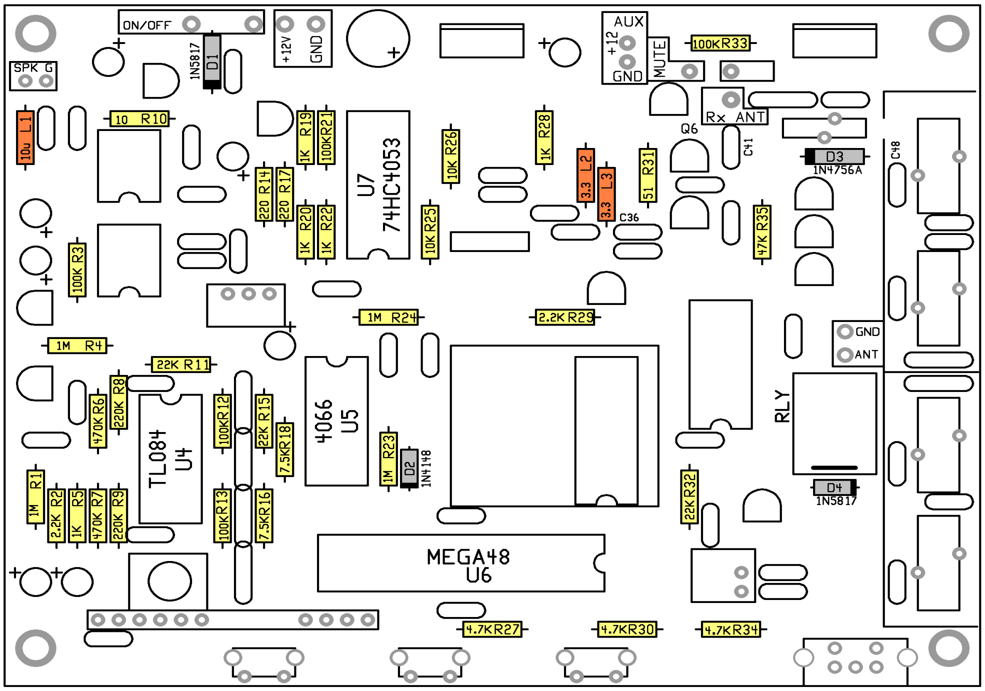


This diagram can be use to help locate a part by it's location designation, which might be a little ambiguous on the board.

Note that parts are numbered in vertical columns, starting at the lower left corner and then zig-zagging to the right side of the board.

Resistors and diodes:

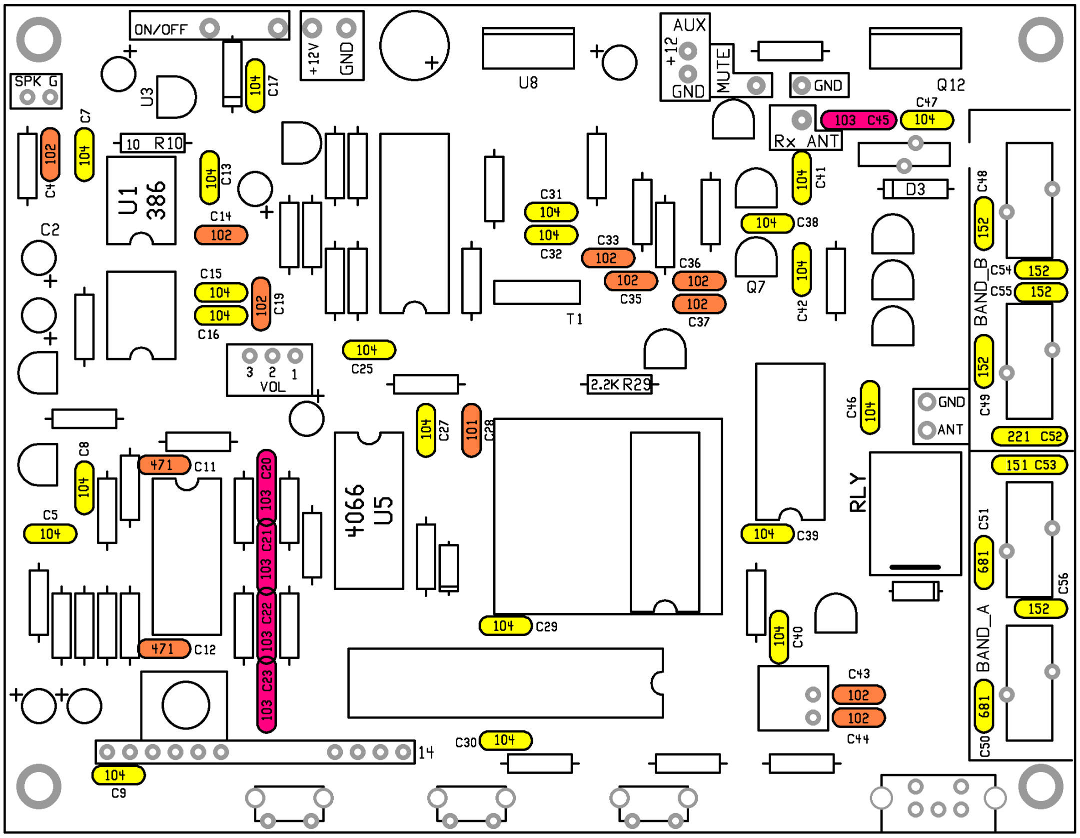
Sorting the resistors by value before you start assembly can speed up the process and help avoid mistakes.



R1	1 MEG	R11	22K	R21	100K	R31	51 OHMS
R2	2.2K	R12	100K	R22	1K	R32	22K
R3	100K	R13	100K	R23	1 MEG	R33	100K
R4	1 MEG	R14	220 OHMS	R24	1 MEG	R34	4.7K
R5	1K	R15	22K	R25	10K	R35	47K
R6	470K	R16	7.5K	R26	10K	L1	10 BRN/BLK/BLK/GLD
R7	470K	R17	220 OHMS	R27	4.7K	L2/L3	3.3 ORG/ORG/GLD/GLD
R8	220K	R18	7.5K	R28	1K	D1/D4	1N5817 large plastic
R9	220K	R19	1K	R29	2.2K	D3	1N4756A large glass
R10	10 OHMS	R20	1K	R30	4.7K	D2	1N4148 small glass

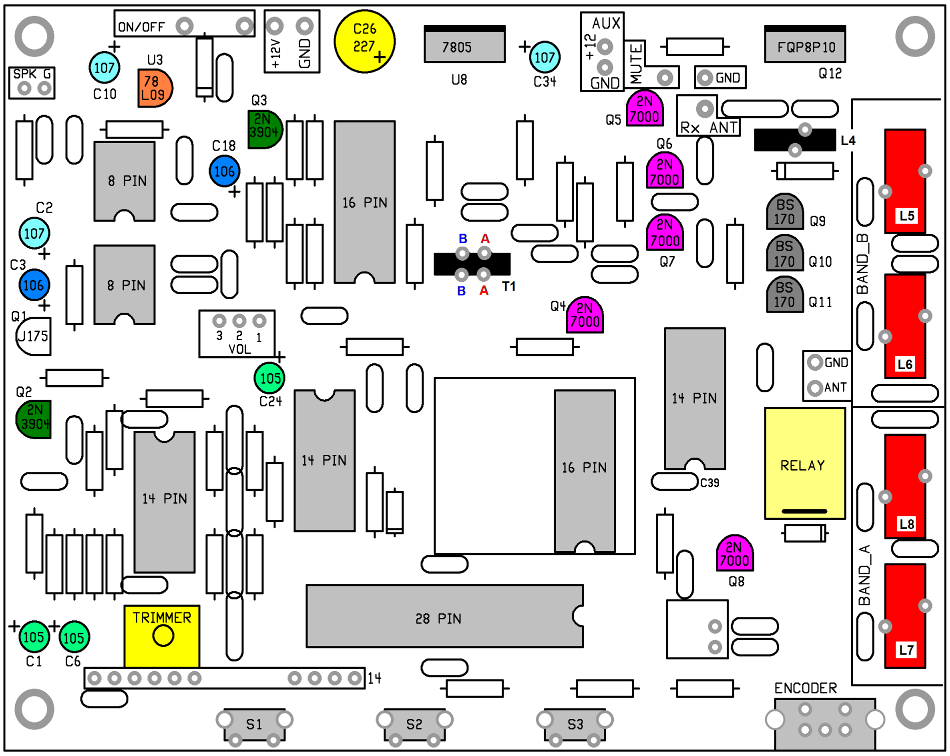
10	BROWN/BLACK/BLACK/GOLD - don't mix up the RFC with the resistor
51	GREEN/BROWN/BLACK/GOLD - CAN BE CONFUSED WITH 1 MEG
220	RED/RED/BROWN/GOLD
1K	BROWN/BLACK/RED/GOLD
2.2K	RED/RED/RED/GOLD
4.7K	YELLOW/VIOLET/RED/GOLD
7.5K	VIOLET/GREEN/RED/GOLD - VIOLET CAN LOOK LIKE BROWN
10K	BROWN/BLACK/ORANGE/GOLD
22K	RED/RED/ORANGE/GOLD
47K	YELLOW/VIOLET/ORANGE/GOLD
100K	BROWN/BLACK/YELLOW/GOLD
220K	RED/RED/YELLOW/GOLD
470k	YELLOW/VIOLET/YELLOW/GOLD
1 MEG	BROWN/BLACK/GREEN/GOLD

Capacitors - ceramic and film



- ✔ 104 (0.1 ufd, MLCC) 21 places - C5, 7, 8, 9, 13, 15, 16, 17, 25, 27, 29, 30, 31, 32, 38, 39, 40, 41, 42, 46, 47
- ✔ 102 (.001 ufd, disk) - 9 places - C4, 14, 19, 33, 35, 36, 37, 43, 44
- ✔ 103 (.01 ufd, film) - 5 places C20, 21, 22, 23, 45
- ✔ 101 (100 pfd, disk) - 1 places - C28
- ✔ 151 (150 pfd, COG) - 1 place - C53
- ✔ 221 (220 pfd, COG) - 1 place - C52
- ✔ 471 (470 pfd, disk) - 2 places - C11, C12
- ✔ 681 (680 pfd, COG) - 2 places - C50, C51
- ✔ 152 (1500 pfd, COG) - 5 places - C48, 49, 54, 55, 56

Sockets, electrolytic caps, transistors, switches and toroids.



Start with the sockets. Make sure you have all the pins through the holes in the board before soldering!!! Also make sure the notch on the socket is orientated with the notch on the location outline.

- ✔ 8 pin, 2 places
- ✔ 14 pin, 3 places
- ✔ 16 pin, 2 places
- ✔ 28 pin, 1 place

Relay: make sure the line on the relay package aligns with the line on the board.

- ✔ Trimmer resistor

Transistors:

- ✔ Q1 - J175
- ✔ Q2, Q3 - 2N3904
- ✔ Q4,5,6,7,8 - 2N7000
- ✔ Q9, 10, 11 - BS170
- ✔ Q12 - FQP8P10 - don't mix up with 5V regulator!
- ✔ U8 - 7805
- ✔ U3 - 78L09

Electrolytic caps:

- ✔ C1, C6, C24 1 ufd (105)
- ✔ C3, C18 - 10 ufd (106)
- ✔ C2, C10, C34 - 100 ufd (107)
- ✔ C26 - 220 ufd (227)

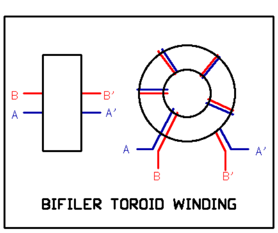
Switches:

- ✔ S1, S2, S3 - Right angle TACT switch. Make sure they are mounted firmly to the board and not tilted or the actuators may not line up with the cabinet holes.
- ✔ Encoder: same thing, make sure it is pressed all the way into the board and is not tilted.

Toroids: remember to tin the leads before soldering into the board.

- L5 = 30 turns (22") T50-2 (RED)
- L6 = 36 turns (26") T50-2
- L7 = 21 turns (17") T50-2
- L8 = 23 turns (18") T50-2
- L4 = 8 turns (6") FT37-43 (Black)

T1 winding:

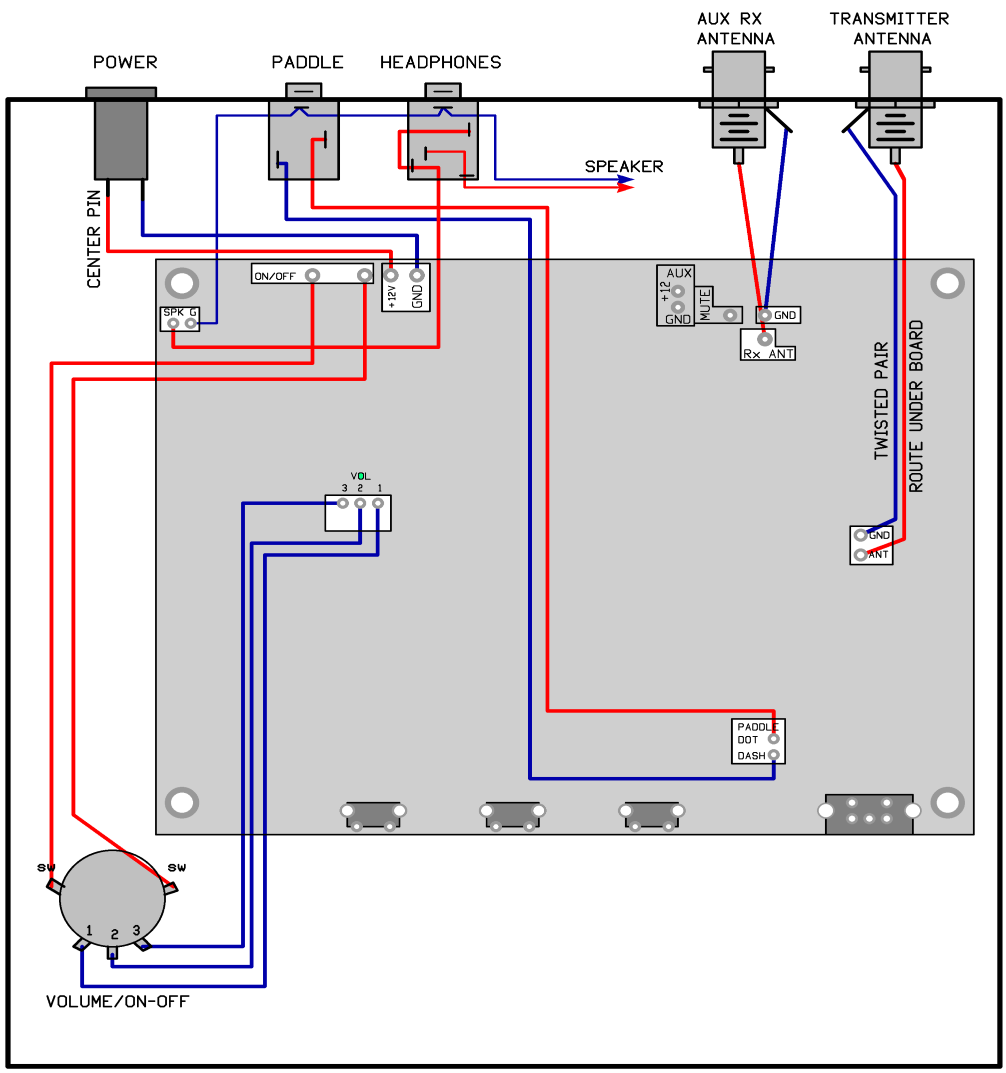


Take a 12" length of magnet wire and fold it in half. The two wires can be lightly twisted together.

- Wind 6 turns around the core. Photo and diagram illustrate the winding and do not indicate the # of turns used in this case. (FT37-43 core, black)
- Snip the wire where it is folded in half to create two wires.
- Tin the wire ends

Find the common ends for each wire with an ohm meter and arrange them so that they are opposite each other on the core as show to the left.

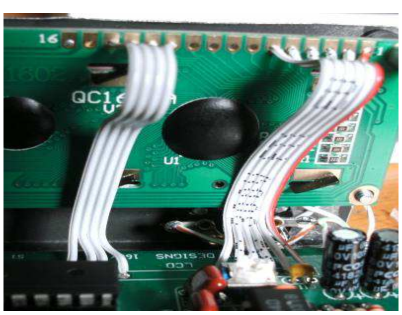
Wiring:



Wires connecting to volume control, the paddle jack and transmitter antenna jack should be routed under the board to keep the wires out of the way. It just looks neater this way.

The wires to the transmitter antenna jack should be twisted together. You'll likely have on one color wire to work with. Making the ground wire an 1" longer then the "hot" wire would allow you to tell the wires apart after they have been twisted together, with out having to resort to an ohm meter to buzz out the ground.

Display wiring:



The LCD is connected to the main board via a length of ribbon cable.

- Separate the cable into two sections:
  - 1 piece, 6 conductors wide
  - 1 piece, 4 conductors wide
- Separate the conductors on both ends of each cable. An Xacto knife is good for doing this.
- Strip and tin the wires ends.
- Use the 6 conductor cable to connect between pads 1 to 6 on the display to the pad on the board 1 to 6.
- Pads 7, 8, 9 and 10 are not used on the display and are not used.
- Use the 4 conductor piece of cable to connect between pads 11 to 14 on the display to the corresponding pads on the board.
- To power the back light, jumpers will need to be added between the back light pads and the power pads.
  - Jumper pad 1 to pad 16 (ground to K, cathode)
  - Jumper pad 2 to pad 15 (+5 to A, anode)

Testing:

To be safe, you should use a fused or current limited power supply at about 1 amp. Minimum operating voltage is about 10.5 volts, full power out at 13.8 volts.

- Install all the IC chips. Pay attention to the orientation as they don't all face the same way and they can be damaged if powered up installed backwards or in the wrong socket. There is a "DOT" or notch on the pin 1 end of the chip which corresponds to the notch in the part outline on the board. Most of the ICs will self destruct if plugged in backwards, so get it right the first time!

  - ✔ U1 - LM386
  - ✔ U2 - LM386
  - ✔ U4 - TL084
  - ✔ U5 - 4066
  - ✔ U6 - MEGA48
  - ✔ U7 - 74HC4053
  - ✔ U9 - 74AC02 (74HC02 maybe supplied)

- Solder the 8 pin row of SIP pins to the DDS module. The short pins go into the board.
- Install the DDS board module. This will plug into the 1 to 8 pins of the 16 pin dip socket. The front end of the board will overhang the MEGA48 chip.

- Connect a 12 to 13.8V power supply to the power connector.
- Turn the power on.
- The display back lighting should come on,
- Adjust the display contrast trimmer, V1, to see the digits on the display. The trimmer is set to mid scale from the factory. It will likely need to be adjusted counter clockwise a little (1/8th turn).

- The display should now be showing the frequency, 3.560,000
- You can now test the controls and switches for proper operation.
- You can connect up an antenna and listen for signals.

Transmitter test:

- Connect a power meter and 50 ohm dummy load to the main, transmitter antenna jack.
- Plug in a straight key with mono plug and turn on power. OR, use a paddle but press the Dash paddle closed as you turn on power to enable straight key mode.
- Key the transmitter and check power output, which should be about 5 watts with a 13.8V supply.
- Switch bands and check power output on 160 M, which should also be about 5 watts.

If you passed all these tests, you are ready to use the rig. If not, check the troubleshooting section and try to find out why it isn't working as it should.

Trouble shooting:

The usual problem with a kit not working is soldering issues, 99 out of a 100 times. Often the problem can be found and solved by a close inspection of all the solder connections.

A common problem is getting solder to stick only to the component lead, but close enough to the pad that it looks like you made a connection. These can be a little hard to spot. A good connection is when you can see both the lead and solder in the hole in the pad it is soldered to. Another thing to look for is solder connections which are missing all together. If you install several parts at a time before soldering, sometimes you can forget to solder one or two leads. Usually you will notice this when clipping the leads, but not always.

Another common problem is not making a connection to the enamel magnet wire used to wind the toroids. The wire must be tinned before soldering to the board. But even when this is done, sometimes the wire is pulled past the tinned area of the wire through the hole and a connection is not made.

Tracking down specific problems:

If there is a problem, narrowing down the area to look is helpful. This is done with a process of elimination by finding out what is working first. That will lead you to what isn't.

- No display, but row of black boxes on top row. - Display not getting data, but has power. Check the connections

between the display and board, check for bent over socket pins on the Processor, U6.

- No transmit or receive. - check DDS chip socket, make sure daughter board is plugged in correctly. You can use another receiver to check for the 1.860 or 3.560 MHz signal which the board should be producing. Check the connections on the transmitter output filter toroids.
- Hiss with volume all the way up, but no signals. The problem could be anywhere in the audio path, which starts at the mixer. An audio signal injector would be handy for tracking through the stages. You could use a computer sound card to generate a tone, or use a MP3 player.
- Receive, but no transmit. - make sure the PA is getting voltage via the Q12 pass transistor.

Typical voltages chart. Voltages are approximate. Voltages on U1 depend on actual supply voltage. Voltages on other chip may vary due to component tolerance, actual output voltage of the regulators and your volt meter loading.

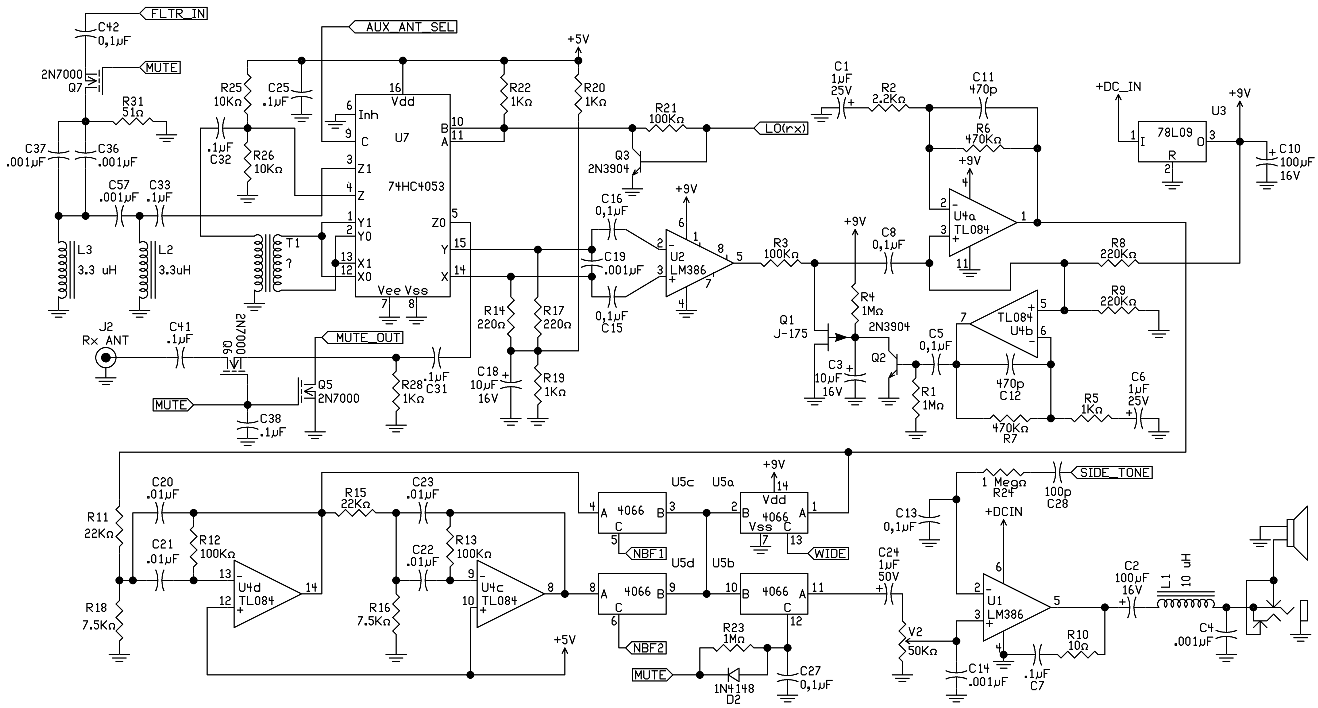
80M band, WB mode, Tx antenna selected for receive.

Pin	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16
U1 LM386	1.4	0	0	0	6.8	13.5	6.5	1.4	-	-	-	-	-	-	-	-
U2 LM386	1.3	0	0	0	4.5	9	4.3	1.3	-	-	-	-	-	-	-	-
U3 78L09	13.5	0	9	-	-	-	-	-	-	-	-	-	-	-	-	-
U4 TL084	4.5	4.5	4.5	9	4.5	4.5	4.5	5	5	5	0	5	5	5	-	-
U5 4066 (WB)	4.5	4.5	4.5	5	0	0	0	5	4.5	4.5	4.5	4.5	5	9		
U7 74HC4053	2.4	2.4	2.5	2.5	0	0	0	0	5	2.5	2.5	2.4	2.4	2.4	2.4	5
U8 7805	13.5	0	5	-	-	-	-	-	-	-	-	-	-	-	-	-
U9 74AC02	0	5	0	0	0	5	0	0	5	0	0	0	5	5	-	-

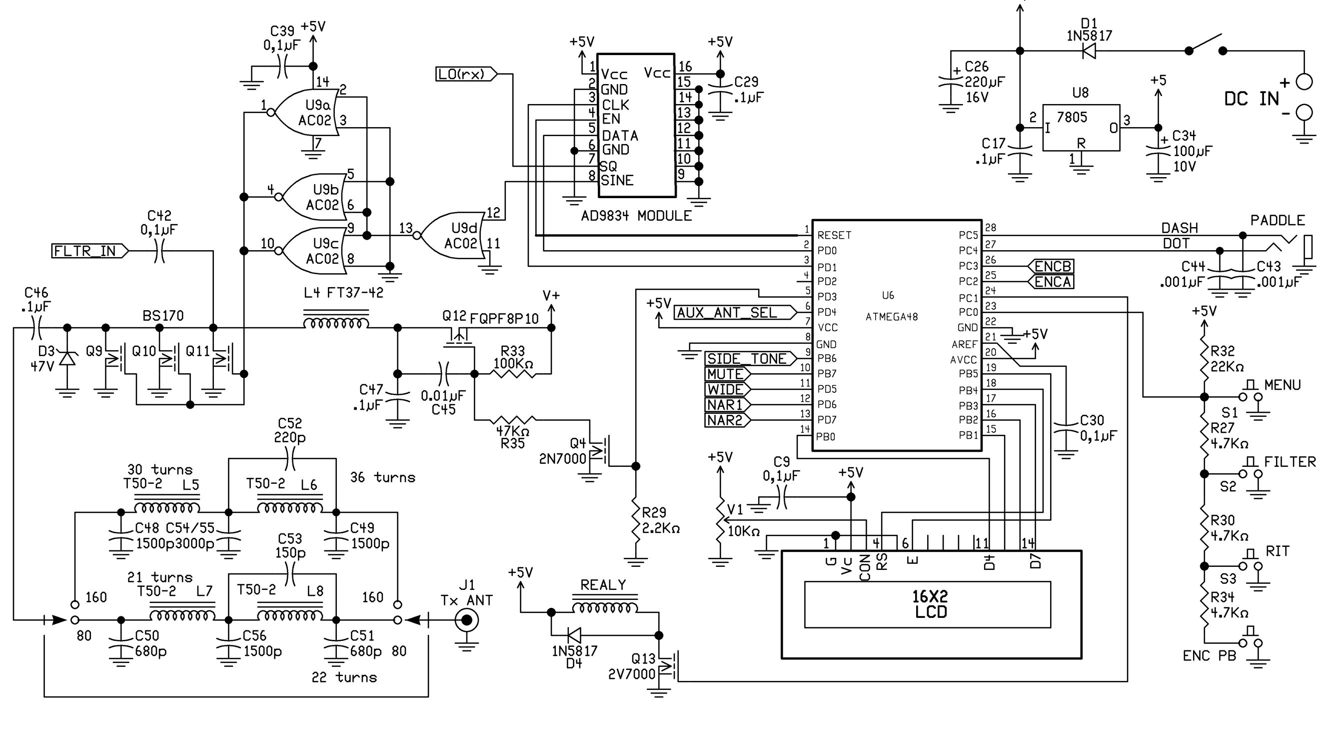
MEGA 48	0	5	5	0	0	5	5	0	5	5	5	0	0	5	
Pins 15-28	5	5	5	5	0	5	0	5	5	0	0	5	0	0	

Schematics:

Receiver section:

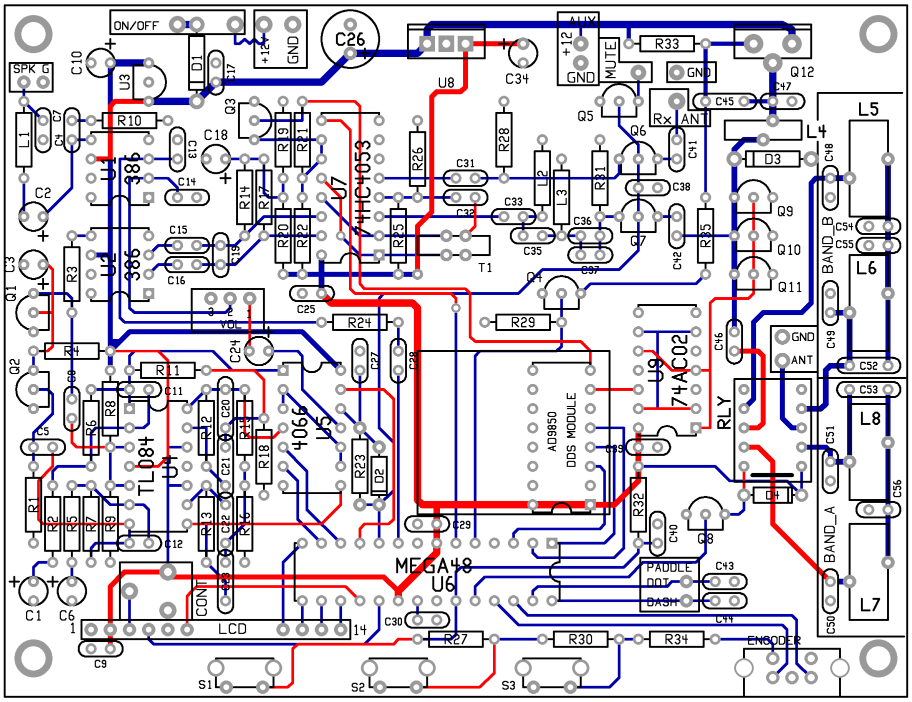


Transmitter and control sections:



Board track layout:

Ground plane not shown for clarity. Most “floating” pads are connected to ground plane.

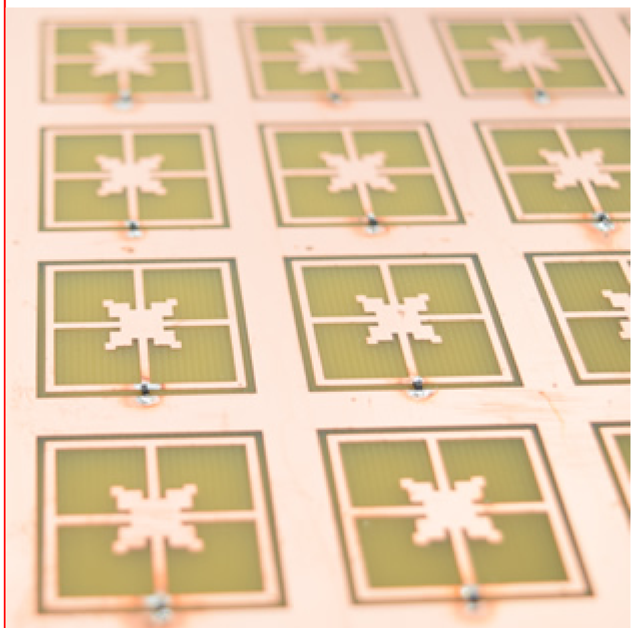


Transmitter filter values for other bands. Note, these use toroids of a different size then those supplied with the kit.

	Value			
	40M	30M	20M	17M
C47 or C48	68 pfd	47 pfd	22 pfd	15 pfd
C44 or C46	330 pfd (331)	220 pfd	150	47 pfd
C49 or C51	680 pfd (681)	560 pfd	330	220 pfd
C45 or C43	330 pfd (331)	220 pfd	150	100 pfd
L2 or L4	18 turns T37-2	13 turns T37-2	13 turns T37-6	13 turns T37-6
L3 or L5	20 turns T37-2	17 turns T37-2	16 turns T37-6	16 turns T37-6

metamaterial devices and applications

back to focus areas ↘



Accelerating innovation by leveraging metamaterials

Metamaterials (i.e., engineered electromagnetic structures), are poised to disrupt industries, create entirely new markets, and change society. The ability to design and fabricate materials with new functionalities opens the door to a new world of possibilities — it is now possible to realize Harry Potter's invisibility cloak and optical black holes, which we once thought was impossible. Beyond the realms of science fiction, metamaterials can be tailored to either augment the functionality of existing devices or create new devices with superior performances.

PARC has been developing a broad array of exciting and impactful metamaterial technology platforms. Today, the metamaterials team is engaged in developing passive radiative cooling (self-cooling films) for buildings and power plant cooling; electronically scanned array platform for drones and self-driving cars; smart metamaterial antennas for 5G networks and satellites; metasurfaces for molding the flow of light; thermal barriers for energy-efficient single pane windows; RF energy harvesting platform for IoT; peripheral nerves/brain focused magnetic stimulation (FMS) technologies; thermophotovoltaics devices; multispectral imaging chemical sensor; defense applications; and a state-of-the-art computational electromagnetics simulation platform.

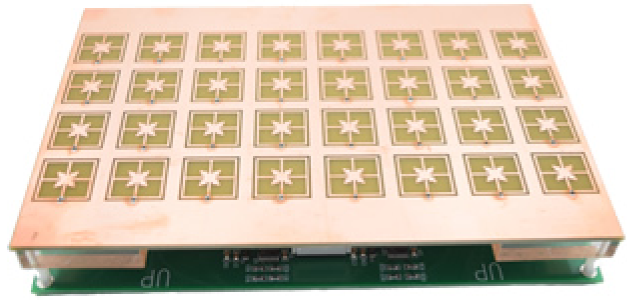
Top row *(left to right): Metamaterial electronically scanned array (MESA); Researchers in the lab; Snapshot of the state-of-the-art applied electromagnetic lab; printed metamaterials RF energy harvesters.*
Bottom row *(left to right): Demonstration of passive radiative cooling indoor; Rooftop measurements setup at PARC; Antennas for cubesats; Arduino device interacting with metamaterial antennas.*

Harnessing high-risk, high-payoff emerging technologies, such as metamaterials, for real-life applications can be a significant challenge to companies. With only academic papers to rely on, companies can become blindsided by emerging technologies. To help our clients capitalize on metamaterials, PARC has assembled a small and highly-coordinated world-class team that evaluates ideas/concepts, brainstorms collectively, builds devices, improves upon existing products, and invents new technology. Underpinned by PARC's innovation framework and in-house design tools with unparalleled performance, our savvy multidisciplinary team solves very hard problems posed by our clients, and works with them at various stages of product development — ranging from feasibility studies to full system prototype. When given seemingly unsurmountable challenges, the team delivers results — with the freedom to approach, own, and solve problems creatively.

The core competencies of the metamaterials team lie in the design/modeling of metamaterials using proprietary tools (e.g., PARSE, AES, FMS^2, DtN, etc.); and fabrication of structures on any surface, flexible or rigid, — using both conventional manufacturing techniques and novel fabrication methods (e.g., printed electronics, additive manufacturing, co-extrusion printing, multi-chip assembler, etc.).

Key Technology Platforms

Metamaterials Electronically Scanned Array (MESA)

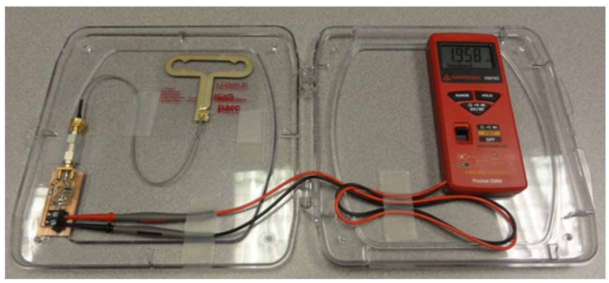


A low-cost, high-performance RF beam steering module that can be adapted for a broad range of applications, including: collision avoidance system for self-driving cars or drones, broadband satellite internet/radio, hypothermia treatment, wireless communications, etc. The key performance feature of PARC's MESA is its capability to maintain a high signal-to-noise ratio and high-resolution, simultaneously.

Smart Metamaterial Antennas

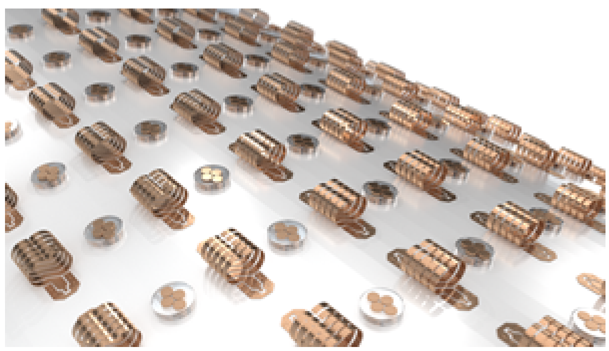
Highly reconfigurable metamaterial antennas are a natural evolution of the MESA architecture. They are tailored for 4G LTE/5G bay stations and for satellite communications.

RF Energy Harvesting Platform



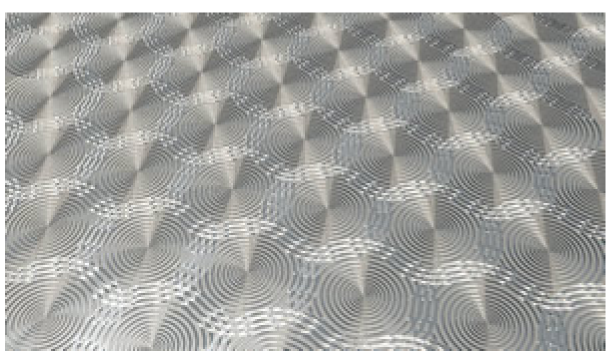
An RF energy harvesting platform that converts Wi-Fi and other RF bands to electricity, to power IoT sensors. It consists of a metamaterial-inspired antenna and a custom rectifying circuit. There are two classes of prototypes that we have demonstrated: hybrid (printed antenna with integrated silicon chips) and all-printed devices. The performance and bandwidth of the RF energy harvesters exceed by at least an order of magnitude that of the state of the art.

Focus Magnetic Stimulation (FMS)



In FMS, the magnetic fields are dynamically shaped by injecting phase and amplitude-controlled currents in an array of three-dimensional micron-scale coils. The FMS scheme enables more localized stimulation (enhanced focusing), better depth control, and complex stimulation patterns (beamshaping and beamsteering), as compared to current magnetic/electric stimulation methods. Tailored stimulations can be obtained with appropriate coil array designs, by selecting the optimal number of elements, array configuration, driving circuits, and current distribution in the coils.

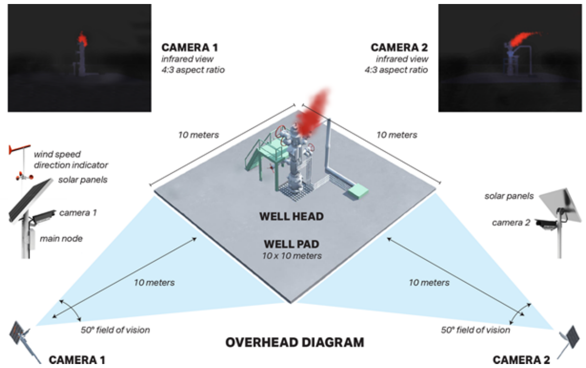
Thermophotovoltaics (TPV)



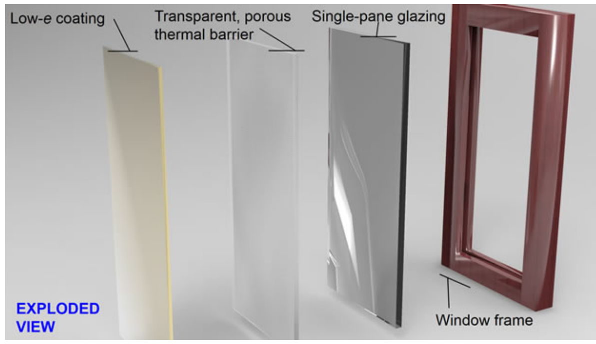
The conversion of thermal radiation emitted from a high-temperature source (the emitter) into electricity by means of a PV cell (e.g., GaSb). PARC's key innovation is a spectrally selective metamaterial emitter that only allows in-band photons to reach the low-bandgap GaSb PV cells for direct electricity conversion. This minimizes thermal losses, which in turn delivers a significant increase in the thermal conversion efficiency.

Multispectral Imaging Chemical Sensor

A chemical sensor system based on a fundamentally new class of uncooled IR imaging sensor that offers the performance of best-in-class, high-end imaging systems at less than 1/10th the cost. This novel thermal platform architecture is designed to remove the limitations (low-sensitivity and no spectral selectivity) of a traditional microbolometer by altering its absorption characteristics. In this architecture, the thermal platform is tailored to exhibit multi-wavelength narrowband absorptions (<0.2 nm linewidths and close to unity absorption) in the infrared. Wavelength selection facilitates fine discrimination between different gases or hydrocarbons (characterized by broad absorptions in the LWIR) based on their spectral responses in each of the narrow bands.

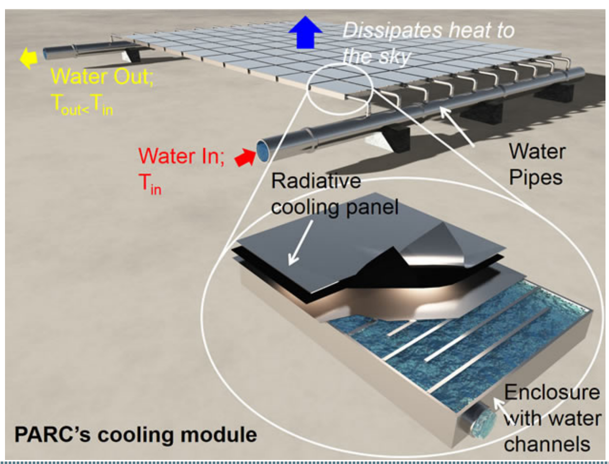


Thermal Barrier



A transparent aerogel polymer material with record low thermal conductivity to prevent thermal losses in single-pane windows. This technology can also be applied as thermal insulation solutions to a variety of industries, including (1) applications where operators or components need to be kept at very stable temperatures (e.g., walls, HVAC ducts, environmental control system (ECS) ducts, etc.); (2) thermal insulation for infrastructure in need of protection from heat (e.g., gas tanks or any other hazardous infrastructure). We also envision the integration of the thermal barrier into reinforced lightweight composite insulation materials, for use as protective coatings of structural components in the automotive, shipboard and aerospace industries.

Passive Radiative Cooling



Low-cost, low-complexity (single layer), highly-scalable films/coatings that can "self-cool" in broad daylight, without the need for electricity or water. This is a new class of materials that molds the flow of heat. Passive radiative cooling can be used for a broad range of applications, including cooling of power plants, buildings, satellites, military tents, and supplies in hot desert climates.

Unique In-House Design Tools

PARC has developed highly-tailored and fast numerical method for computational design and discovery problems in electromagnetics. We have the capability to develop new codes based on specific EM problems and requirements. These methods allow full design space explorations (parsing up to billions of structures in a day), and enable efficient global and local optimizations without human intervention. These new in-house design tools, used in conjunction with commercial code, have been shown to be accurate through experimental verification.

PARSE

PARC's Advanced Robust Solver for Electromagnetics is a fast frequency domain solver tailored for solving the linear Maxwell's equations in layered periodic structures. Internally, it has a core Rigorous Coupled Wave Analysis engine [RCWA; also called the Fourier Modal Method (FMM) and the S-matrix algorithm], and makes use of black box optimization algorithms. PARSE can compute transmission, reflection, or absorption spectra of structures composed of periodic, patterned, planar layers. So far, its speed has been unmatched (benchmarked against off-the-shelf and open codes) for problems involving periodic structures and multilayer dielectric stacks (10-100X+ speed improvements). It has been tailored to leverage multi-nodes workstations and GPUs. In PARSE, the EM fields throughout the structure, as well as certain line and volume integrals, can also be obtained. The spectra obtained from the core engine are amenable to local

and global optimizations. PARSE uses brute force optimization, which means that it parses billions of structures in a single day, to achieve an analog of inverse design (i.e., figuring out the exact geometry given a desired functionality). PARSE's framework for shape calculus allows for quickly finding superior, non-intuitive designs.

AES

Absorber Electromagnetic Solver is a tailored Fourier-based solver for radar-absorbing metamaterials, which computes absorption spectrum 130 times faster than commercial electromagnetic solvers. The basis functions in AES are computed once, and then reused for all frequencies, thicknesses, and materials parameters. AES, like all tailored design tools, focuses on a particular problem type (metal-dielectric-metal stacks with top patterned layer). In AES, the expanded currents and fields are directly computed in Fourier domain, i.e., no expensive numerical integrals or Green's function evaluations are carried out. AES has a fast kernel that can be exploited to quickly and efficiently identify optimal structures (i.e., topology optimization) to achieve desired performance.

FMS^2

Focus Magnetic Stimulation Solver is a tailored tool for simulating the magnetic fields of 2D and 3D coils. It was built for designing, modeling, and optimizing PARC's focused magnetic stimulation (FMS) magnetic micro-coils scheme. Internally, it solves Biot-Savart and Ampère's law equations quickly and efficiently.

DtN

Dirichlet-to-Neumann map is a domain decomposition scheme. The DtN method is specifically tailored for simulating photonic crystal devices with many repeated unit cells. In DtN, only the fields at the edge of every unit cell of the photonic crystal is stored, as opposed to everywhere in the interior as in a number of EM solvers. This allows DtN to explore very large parameter spaces efficiently, generate statistics about the parameter space, and systematically optimize geometries.

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Article

Optimization of Passive Low Power Wireless Electromagnetic Energy Harvesters

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Abstract: This work presents the optimization of antenna captured low power radio frequency (RF) to direct current (DC) power converters using Schottky diodes for powering remote wireless sensors. Linearized models using scattering parameters show that an antenna and a matched diode rectifier can be described as a form of coupled resonator with different individual resonator properties. The analytical models show that the maximum voltage gain of the coupled resonators is mainly related to the antenna, diode and load (*remote sensor*) resistances at matched conditions or resonance. The analytical models were verified with experimental results. Different passive wireless RF power harvesters offering high selectivity, broadband response and high voltage sensitivity are presented. Measured results show that with an optimal resistance of antenna and diode, it is possible to achieve high RF to DC voltage sensitivity of 0.5 V and efficiency of 20% at −30 dBm antenna input power. Additionally, a wireless harvester (*rectenna*) is built and tested for receiving range performance.

Keywords: RF energy harvesting; wireless power transmission; coupled resonators; Schottky diode; RF to DC power converter; impedance matching; PI-matching; L-matching; rectenna

1. Introduction

For autonomous powering of sensor nodes in remote or inaccessible areas, wireless power transfer provides the only viable option to power them from an energy source. Due to the low power density of ambient RF at far-field from transmitters, there is a need to optimize each aspect of a wireless RF energy harvester for possible realistic applications. Today remote autonomous sensors are mostly powered by batteries, which have limited lifespan. Renewable powering has the potential to power autonomous sensors perpetually. Due to the expansion of telecommunications technology ambient electromagnetic (EM) power is among the most common sources of ambient energy. There are power transmitters/receivers scattered in practically any society, ranging from television transmission stations to cell phone transmitters and even wireless routers in our homes/offices or mobile phones. These transmitters in our environment and others which are on special dedicated frequencies produce ambient RF power (on the order of microwatts) which can be used as a source for powering remote microwatt budget sensors through wireless energy harvesting. This work presents different matching techniques based on different application requirements using Schottky diode-based RF to DC power converting circuits for wireless remote EM energy harvesting around 434 MHz and 13.6 MHz. Generalized analytical models and limitations of the matched RF to DC power converters are discussed. A wireless RF energy harvester consisting of an antenna and a matched diode rectifier is then realized and its performance tested. Passive wireless energy harvesting also finds applications in near field communications (NFC) [1], RFID tags [2–5], implantable electronics [6,7], and environmental monitoring [8], among others.

1.1. State of the Art

Hertz was the first to demonstrate the propagation of EM waves in free space and to demonstrate other properties of EM waves such as reflection using parabolic reflectors [9]. Wireless power transmission was then investigated and demonstrated for possible wireless remote powering by Tesla. Electromagnetic power beaming for far field wireless power transfer using collimated EM waves was proposed in the 1950s [9]. Recent advances in ultralow power sensors means ambient omni-directional EM power can be used as a source for powering remote sensors without the need to collimate the EM power through the wireless space. Mickle [10] and McSpadden [11] have presented earlier work on wireless energy harvesting systems using Schottky diodes and rectennas where the usability of ambient RF power into DC power was shown. Sample [12] presented a wireless harvester which can harvest EM power from TV and radio base stations transmitting 960 kW of effective radiated power; 60 μW was harvested at a range of about 4 km. Umeda [13] and Le [14] have presented more integrated wireless energy harvesters based on CMOS RF to DC rectifying circuits. CMOS-based rectifying power converters provide full compatibility with standard CMOS technologies and have advantages in batch processes for mass production. The drawback of CMOS-based diode connected transistors is the need to bias the gate of the transistors for the rectifying circuits to effectively function. This gate bias is provided externally, which makes the system not passive. Without the injection of external charges or a biasing of the transistor gate, the circuit has low efficiency, especially when the amplitude of the input voltage is low [15]. Shameli [2] presented a passive CMOS RF to DC power converter with a

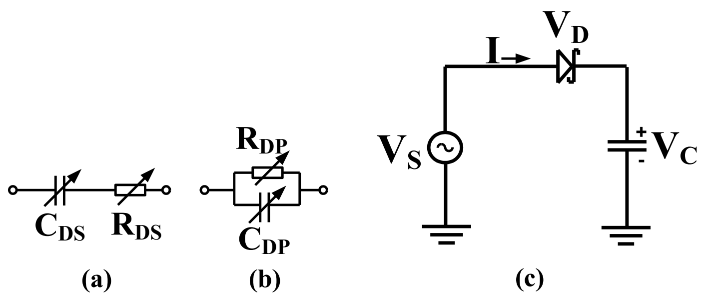
voltage sensitivity of 1 V at −14.1 dBm input, but the circuit efficiency was only 5 %. Zbitou [16] presented an RF to DC converter based on Schottky diodes and achieved 68 % efficiency at 20 dBm RF input power. Ungan [17,18] presented antennas and high quality factor RF to DC power converters at 24 MHz and 300 MHz for RF wireless energy harvesting at -30 dBm input power. The power converter used high quality factor resonators for impedance matching the EM source and the diodes and achieved high open circuit voltage sensitivity of 1 V/μW. Boquete [19] presented a risk assessment system for calculating insurance premiums by monitoring mobile phone usage while driving. This was done by harvesting EM power from detected mobile phone usage during driving for risk assessment. Heikkinen [20] presented rectennas on different substrates at 2.4 GHz using transmisson lines to match the antennas output resistance (*at resonance*) to the rectifying diodes. Akkermans [21] presented a rectenna design by complex conjugating impedance provided by a microstrip structure to a diode so that resonance may be achieved for a working frequency. This design approach may need sophisticated tools to realize and the dominant resonance frequency of the rectenna can be unpredictable in practice. Hagerty [22] presented rectenna arrays for broadband ambient EM harvesting and characterized the harvesters from 2 GHz to 18 GHz; rectennas combine impedance matching the RF rectifying circuit and the antenna into one compact device, but an array of rectennas may increase the overall size of an EM harvester. Herb [23] and Vullers [24] have provided a comprehensive state of the art for micro energy harvesting and have explored the various techniques used for harvesting ambient renewable energy.

2. RF to DC Power Converter

2.1. Diode Rectifier

A junction diode equivalent circuit and simple Schottky diode rectifier are shown in Figure 1. R_{DS} is the diode resultant series resistance, C_{DS} is the diode resultant series capacitance, R_{DP} is the diode resultant parallel resistance, C_{DP} is the diode resultant parallel capacitance, V_S is the sinusoidal source voltage and V_C is the voltage across the capacitor.

Figure 1. (**a**) Diode series equivalent model, (**b**) Diode parallel equivalent model, (**c**) Simple diode detector.



The diode capacitive impedance is mainly due to the junction capacitances provided by the metal, its passivation and the semiconductor forming the diode. AC power incident on a forward biased diode input is converted to DC power at the output. The current-voltage behavior of a single metal/semiconductor diode is described by the Richardson equation [25] as in Equation (1):

$$I = I_S\left(e^{\left(qV_D/_{nKT}\right)} - 1\right) \tag{1}$$

where I is the current through the diode, I_S is the saturation current, q is the charge of an electron, V_D is the voltage across the diode, T is the temperature in degrees Kelvin and K is Boltzmann constant. The voltage equation around the loop can be derived from Figure 1(c) and is given in Equation (2):

$$V_D = V_S - V_C \tag{2}$$

Since the same current flows through the diode and the capacitor, one can find the average current through the circuit by integrating Equation (1) over a time period. By substituting Equation (2) into Equation (1), V_C can be expressed in terms of V_S by averaging the diode current to zero. This is given in Equation (3) [26]:

$$V_C = \frac{KT}{q}\ln\left[\vartheta_0\left(\frac{qV_S}{KT}\right)\right], \tag{3}$$

where ϑ_0 is the series expansion of the sinusoidal source voltage. Equation (3) can further be simplified for very small amplitude V_S as Equation (4):

$$V_C \approx \frac{qV_S^2}{4KT} \tag{4}$$

Equation (4) shows that for a small voltage source, the circuit output voltage is proportional to the square of the input sinusoidal voltage; hence it's so-called square law operation. Extensions of this model for voltage multipliers and other input signals are presented in [27] and [28]. Equation (4) further confirms that for low input voltage (power $\leq$ 10 dBm), an impedance matching network between the source and the diode is necessary to improve the detected output voltage and efficiency.

2.2. Impedance Matching

The maximum power transfer theorem states that the highest power is transferred to the load when the source resistance is the same as the load resistance. For systems with both resistive and reactive impedances from source and load, the source and the load impedance should be adjusted in a way that they are the complex conjugate of each other through impedance matching. For the purposes of this work, a 50 Ω resistive source is chosen as reference for load impedance matching. The antenna which captures the ambient RF signals is tuned to provide this source resistance at resonance for the rectifying circuit in a complete EM wireless remote harvester. The load is the resistance of the Schottky diodes and the actual connected resistance (*remote sensor*). The specific type of matching network which can be used for complex conjugation depends on the nature of load or source impedance, the desired RF to DC converter functionality and other factors like circuit size, cost, *etc.* The response of a matched RF to DC power converter depends on the matching network used as well as the source or load component quality factors and impedances.

2.3. Diode Impedance

Schottky diodes HSMS-285C and HSMS-286C from Avago [29,30] are used to build the RF to DC power converters. The HSMS-285× or 286× series diodes can be operated as zero biased with relatively low forward junction potential. This allows for the realization of completely passive RF to DC power converters for wireless energy harvesting. The HSMS-285C or 286C is a pair of series connected Schottky diodes in a SOT-323 package. The impedance of the HSMS-285C and HSMS-286C diodes was first measured so it can be matched to the resistance (50 Ω) of the antenna source. This is done by connecting the input of the diodes to a network analyzer and measuring the scattering parameters. These scattering parameters are then converted to the corresponding impedances. The input impedance of a diode depends mainly on the resistive and capacitive impedance provided by the junction of the diode and its connected load. For a couple of diodes arranged in a package such as the HSMS-285C or 286C, the input impedance is the vector sum of the impedances provided by each diode in the package arrangement, the extra impedance associated with the packaging and the connected load. The diode measuring board is as shown in Figure 2. The diodes were measured at room temperature for an input power of -30 dBm at a diode connected load of 1 MΩ with a 100 pF filter capacitor. For the sake of this work, the input impedance of the diodes will always be referred to at these connected load conditions.

Figure 2. (**left**) Reference circuit layout for measuring diodes input impedance, (**right**) measuring printed circuit board (PCB) for diodes input impedance on 1 mm FR4 substrate.

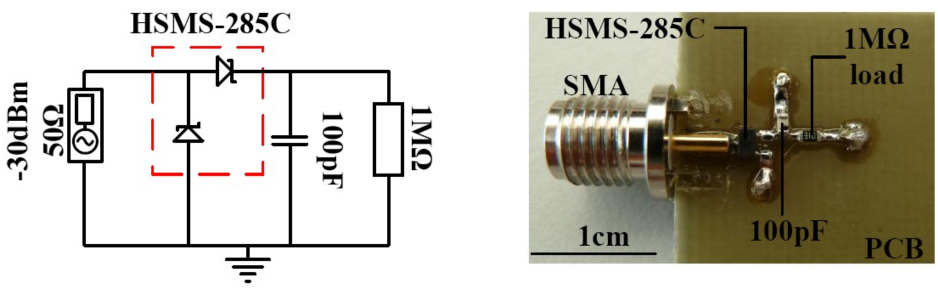
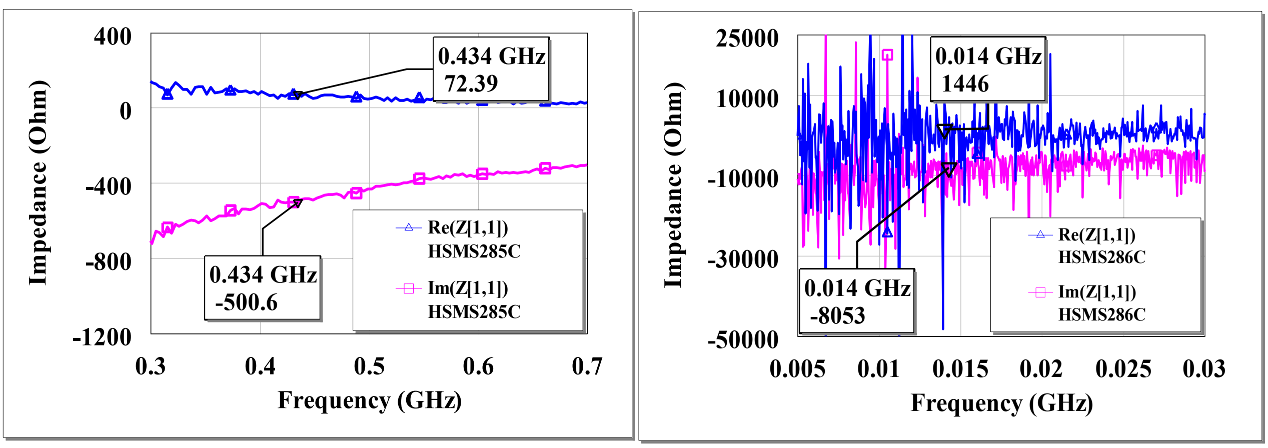


Figure 3. Measured input impedance (Δ resistive, □ capacitive) of HSMS-285C (**left**) and HSMS-286C (**right**) diodes at −30 dBm input with 1 MΩ load and 100 pF filter.



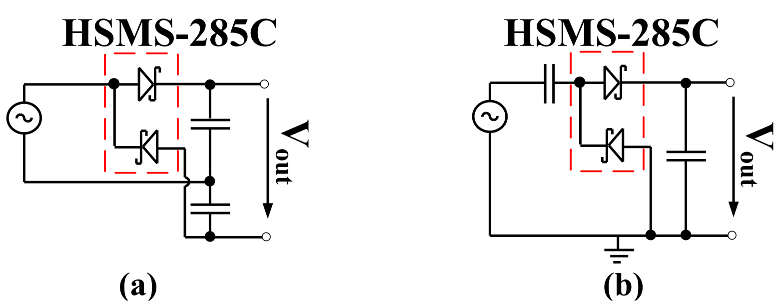
The board is fabricated such that components are soldered directly one into another to prevent additional impedances introduced by copper route. The PCB backside had the ground layer. An example of measured input impedance for HSMS-285C and HSMS-286C is shown in Figure 3.

The diodes quality factor is given by $X_{DS}R_{DS}^{-1}$, where X_{DS} is the resultant series capacitive impedance of the diodes. At an input power of −30 dBm, the measured input impedance of the HSMS-285C diodes is 72–j501 Ω at 434 MHz and 587–j1239 Ω at 13.6 MHz. For HSMS-286C diodes, it is 10–j503 Ω at 434 MHz and ~1.5–j8.1 kΩ at 13.6 MHz for −30 dBm input. The measured impedance of the HSMS-286C diodes at low frequencies (< 60 MHz) shows pronounced fluctuations. The low-frequency excess flicker noise and the shot noise observed in the HSMS-286C have been studied by several authors [31–33]. The pronounced presence of trap states in the depletion region of the semiconductor, mobility fluctuations in carriers, edge effects among other reasons is reported to cause deviations from the ideal Schottky diode behavior and hence generation-recombination noise for some diodes such as the HSMS-286C [34]. When a diode rectifier is matched at a reference operating condition, the matching network may function less effectively at other input power levels, connected load and other operating frequencies. This is due to possible changes in the diode input impedance. Throughout this work the imperfections of the matching circuit at other operating conditions away from the matched reference conditions are accepted without changes to the matching network.

2.4. Voltage Doubler

The Delon voltage doubler and Greinacher doubler are both used to realize the RF to DC power converters presented in this work. The Delon voltage doubler and Greinacher doubler are shown in Figure 4. The diodes output voltage (V_{out}) is doubled what is detected by a simple detector circuit shown in Figure 1. Both doublers produce the same output performance, the only difference is that the Delon doubler has an instantaneous input ground which is not shared with the output.

Figure 4. Circuit diagram of voltage doubler, (**a**) Delon doubler and (**b**) Greinacher doubler.



2.5. Matching Techniques for Antenna Source and RF to DC Power Converter

2.5.1. L-match RF to DC Power Converter

An L-match network converts a source series impedance to its equivalent load parallel impedance or *vice-versa* and tunes out by subtracting or adding any surplus reactance from the load or source with the counter impedance. Series impedance is converted to its parallel equivalent impedance using Equations (5–7):

$$Q_S = \frac{X_S}{R_S} \tag{5}$$

$$Q_P = \frac{R_P}{X_P} \tag{6}$$

where *Xs* is the total series reactive impedance, *Rs* is the total series resistance, R_P is the total parallel resistance, *Xp* is the total parallel reactive impedance, Q_S and *Qp* are the series and parallel quality factors respectively:

$$R_S + jX_S = \frac{R_P \times jX_P}{R_P + jX_P} \tag{7}$$

Equation (7) is the equation of a series sum of impedances and a parallel sum of impedances. It is interesting to note that Q_S and Q_P from an L-matched network may be different from the individual component quality factors as a result of the inherent resistive and reactive impedances in that component. By virtue of Equation (7), Q_S and Q_P must be equal in an L-matched network. Using Equations (5,6) and (7), the ratio of the parallel resistance (*or reactance*) to the series resistance (*or reactance*) can be derived in terms of the quality factors Q_P or Q_S [35]. Since at match conditions, only the resistive impedances dissipate power, the loaded quality factor *Q,* of the L-matched network can be expressed as in Equation (8):

$$R_P = (Q^2 + 1)R_S \tag{8}$$

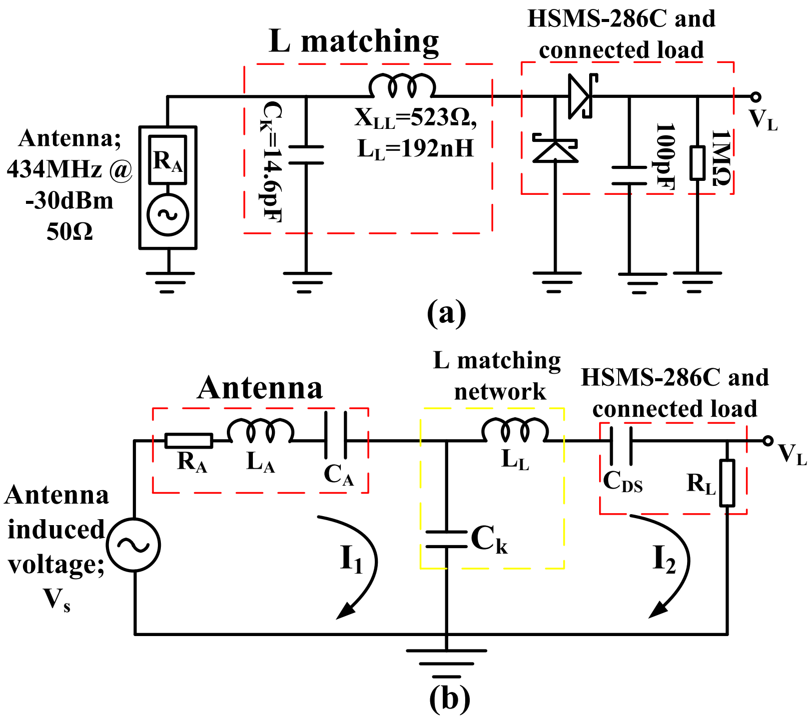
Using Equations (5,6) and (8), series impedance can be converted to its parallel equivalent for a fixed frequency and power level. As an example; a series impedance 72–j501 Ω (HSMS-285C at 434 MHz for −30 dBm input power) is easily converted to −*j*510(3519)/(−*j*510 + 3519) Ω as its parallel equivalent with a component quality factor of 6.96. The source resistance is taken as part of the parallel matching network in an L-match circuit if the source series equivalent resistance is greater than the load series equivalent resistance. On the other hand, the load resistance is taken as part of the parallel matching network if the load series equivalent resistance is greater than the source series equivalent resistance. For the purpose of this work, inductors were only used for series impedance matching and capacitors as shunts. This prevents power seeping through any shunt inductor used for impedance matching due the short circuit provided by a shunt inductor to ground and resulting in less output efficiency. Resistors were not used for impedance matching.

2.5.2. L-match RF to DC Converter Generalized Analytical Model

The classical matching technique using Equations (5,6) and (8) is first used to L-match the 50 Ω resistance of the antenna to the resistance of the HSMS-286C diodes (and load) at 434 MHz for −30 dBm input and then the generalized model is discussed. The antenna source resistance was L-matched to the resistance of the diodes (and load). The 50 Ω resistance of the antenna is taken as the parallel matching component and the diodes 10 Ω resistance is the series matching component. The loaded *Q* is found as 2 between the 50 Ω antenna source resistance and the 10 Ω diode series resistance using Equation (8). From this loaded *Q*, a shunt capacitive impedance of 25 Ω (14.6 pF at 434 MHz) using Equation (6) and a series inductive impedance of 20 Ω (7.3 nH at 434 MHz) using Equation (5)

will match the 50 Ω source to the 10 Ω HSMS-286C diodes (and load) series resistance at −30 dBm input. Since the HSMS-286C diodes inherently provides 503 Ω series capacitive impedance at −30 dBm, a resultant series inductive impedance of 523 Ω (192 nH at 434 MHz) is needed to tune the 50 Ω resistive source to the complete HSMS-286C diodes impedance at 434 MHz for −30 dBm input. The L-matched HSMS-286C diodes rectifier is as shown in Figure 5(a).

Figure 5. (**a**) L-match RF to DC harvester using the HSMS-286C diodes at 434 MHz for −30 dBm input. (**b**) Small signal impedance model of a generalized L-matched RF to DC power converter as capacitive coupled series RLC resonator with different resonator elements.



C_K is the tuning capacitance, L_L is the tuning inductance, X_{LL} is the tuning inductive impedance, C_{DS} is the diodes series capacitance, X_{DS} is the diodes series capacitive impedance, V_S is the antenna captured ambient EM voltage, R_A is the resistance of antenna, L_A is the inductance of antenna, C_A is the capacitance of antenna, R_L is the resultant series resistance from the diodes and the connected load resistance, V_L is the resistive load voltage. From Figure 5(a) the power dissipated in the resistance of the diodes (and connected load); P_L is given by Equation (9), where R_L is the series resistance of the diodes and load:

$$P_L = \frac{V_L^2}{R_L} \tag{9}$$

The source power; P_S is given by Equation (10), where V_S* is the root mean squared (RMS) antenna captured source voltage. Half of the source power is transferred to the resistance of the diodes (and connected load) at match conditions as described by the maximum power transfer theorem:

$$P_S = \frac{V_S^2}{R_A} \quad \text{or} \quad P_S = \frac{V_{S*}^2}{2R_A} \tag{10}$$

Equating P_L and half RMS P_S gives a condition of maximum voltage gain for the matched RF to DC power converter shown in Figure 5(a):

$$\frac{V_L}{V_{S*}} = \frac{1}{2}\sqrt{\frac{R_L}{R_A}} \tag{11}$$

From Equation (8), substituting the series and parallel resistance ratio into Equation (11) the voltage gain can be expressed in terms of the loaded quality factor as in Equations (12) and (13), where Q is the loaded quality factor of the RF to DC power converter:

$$\frac{V_L}{V_{S*}} = \frac{1}{2}\sqrt{\frac{1}{1 + Q^2}} \tag{12}$$

Equation (12) is the voltage gain in-terms of the loaded Q if the resistance of the diodes (and connected load) is part of the series matching network and the resistance of the antenna source is part of the parallel matching network as in Figure 5(a). If the resistance of the diodes is part of the parallel matching network, then Equation (13) may be written as the voltage gain in-terms of the loaded Q in an L-matched circuit:

$$\frac{V_L}{V_{S*}} = \frac{1}{2}\sqrt{1 + Q^2} \tag{13}$$

Equations (12) and (13) shows that the maximum voltage gain is directly related to the relative differences between the diodes (and connected load) resistance and source resistance at matched conditions or the circuit loaded quality factor. It is interesting to note that the circuit shown in Figure 5(a) has a loaded Q of 2, but an HSMS-286C unloaded quality factor of 50 (at 434 MHz for −30 dBm).

Figure 5(a) is generally modeled as capacitive coupling of two series RLC resonators with a voltage source. This linearized model can be made at any defined frequency and power level. The model however neglects the metal/semiconductor physics of the diode's junction potentials which results in a Schottky barrier. The first series RLC resonator is modeled as impedance from the antenna with or without some passive matching components. The voltage source V_S, is the antenna captured electromagnetic voltage. The second series RLC resonator is the impedance from the diodes (at a defined condition), connected resistance and some passive matching components. Ck is modeled as the coupling element between the two series RLC resonators. Figure 5(b) gives a more general look at the special scenario shown in Figure 5(a). The voltage equations in the two loops are given by Equations (14,15) according to Kirchhoff's voltage loop laws, where ω is the angular frequency and I_1, I_2 are the currents in the first loop and second loop, respectively:

$$V_S = I_1\left[R_A + j\omega L_A - \frac{j}{\omega C_A} - \frac{j}{\omega C_K}\right] + \frac{jI_2}{\omega C_K} \tag{14}$$

$$0 = \frac{jI_1}{\omega C_K} + I_2\left[R_L + j\omega L_L - \frac{j}{\omega C_{DS}} - \frac{j}{\omega C_K}\right] \tag{15}$$

Using Cramers rule, I_2 can be expressed as:

$$I_2 = \frac{\dfrac{-jV_S}{\omega C_K}}{\left[R_A + j\omega L_A - \dfrac{j}{\omega C_A} - \dfrac{j}{\omega C_K}\right]\left[R_L + j\omega L_L - \dfrac{j}{\omega C_{DS}} - \dfrac{j}{\omega C_K}\right] + \dfrac{1}{\omega^2 C_K^2}}. \tag{16}$$

The voltage across R_L is V_L; given by $I_2 R_L$:

$$V_L = \frac{\dfrac{-jV_S}{\omega C_K} R_L}{\left[R_A + j\omega L_A - \dfrac{j}{\omega C_A} - \dfrac{j}{\omega C_K}\right]\left[R_L + j\omega L_L - \dfrac{j}{\omega C_{DS}} - \dfrac{j}{\omega C_K}\right] + \dfrac{1}{\omega^2 C_K^2}} \tag{17}$$

The voltage gain of the coupled resonator can be expressed as in Equation (18):

$$\frac{V_L}{V_S} = \frac{\dfrac{-jR_L}{\omega C_K}}{\left[R_A + j\omega L_A - \dfrac{j}{\omega C_A} - \dfrac{j}{\omega C_K}\right]\left[R_L + j\omega L_L - \dfrac{j}{\omega C_{DS}} - \dfrac{j}{\omega C_K}\right] + \dfrac{1}{\omega^2 C_K^2}} \tag{18}$$

At resonance, there is no resultant reactance in the RLC resonators or the capacitive and inductive impedances become equal; hence Equation (19) can be written:

$$\omega L_A - \frac{1}{\omega}\left\{\frac{1}{C_A} + \frac{1}{C_K}\right\} = 0 \text{ and } \omega L_L - \frac{1}{\omega}\left\{\frac{1}{C_{DS}} + \frac{1}{C_K}\right\} = 0 \tag{19}$$

Equations in Equation (19) can be used to find the resonant frequencies of the series coupled resonator. The voltage gain of the coupled resonator at resonance can then be expressed as in Equation (20):

$$\frac{V_L}{V_S} = V_{gain} = \frac{\dfrac{-jR_L}{\omega C_K}}{R_A R_L + \dfrac{1}{\omega^2 C_K^2}} \tag{20}$$

where V_{gain} is the voltage gain. V_{gain} at resonance is a function of the resistance of the source and load and the coupling element. The maximum of Equation (20) is obtained when:

$$\frac{dV_{gain}}{dC_K} = 0. \tag{21}$$

This gives the results as in Equation (22):

$$\frac{dV_{gain}}{dC_K} = \frac{j2R_L}{\omega^3 C_K^4} - j\left\{R_A R_L + \frac{1}{\omega^2 C_K^2}\right\}\frac{R_L}{\omega C_K^2} = 0 \text{ or } R_A R_L^2 = \frac{R_L}{\omega^2 C_K^2} \tag{22}$$

Equation (22) can be simplified to find $C_{K(max)}$:

$$C_{K(\max)} = \pm\frac{1}{\omega}\sqrt{\frac{1}{R_A R_L}} \tag{23}$$

where C_{Kmax} is the value of the coupling element where maximum power transfer from the first resonator to the second resonator occurs. Using Equations (19) and (23) the unknown optimal matching impedances can be found from the known impedances just like the classical L-matched procedure using Equations (5,6) and (8). By substituting $C_{K(max)}$ into Equation (20) and taking the magnitude of V_{gain}, gives the maximum voltage gain of the coupled series resonator at resonance:

$$\left|\frac{V_L}{V_S}\right| = \frac{1}{2}\sqrt{\frac{R_L}{R_A}} \text{ or simply } \frac{V_L}{V_{S*}} = \frac{1}{2}\sqrt{\frac{R_L}{R_A}} \tag{24}$$

For wireless harvesters consisting of an antenna and a diode rectifying circuit, the diode resistive impedance at any condition is dependent on the diode realized parameters, signal frequency, connected load and the input power level. The source impedance is determined by the impedance of the antenna. For maximum efficiency, the ratio of the source resistance to the load resistance must tend to zero at matched conditions. The efficiency η of the circuit is given by Equation (25):

$$\eta = \frac{P_L}{P_S}\,;\, \eta \rightarrow 1 \;\; when \; \frac{R_A}{R_L} \rightarrow 0 \tag{25}$$

2.5.3. L-Match RF to DC Converter Experimental Results and Discussion

The presented circuit was L-matched between the 50 Ω resistance of the antenna source and the resistance of the HSMS-285C diodes (and load) at 434 MHz for −30 dBm input as shown in Figure 6. Since the series equivalent resistance of the HSMS-285C diodes and load (72 Ω) is greater than the 50 Ω series resistive antenna source, the diode is taken as parallel matching network with a parallel equivalent impedance of $-j510(3519)/(-j510 + 3519)$ Ω. The analysis follows the same procedure as in Section 2.5.2 after this step. Figure 6(b) shows the resultant L-matched RF to DC power converter. C_{DP}* is the resultant shunt matching capacitance.

Figure 6. (**a**) L-matched impedance circuit for matching the HSMS-285C diodes at 434 MHz for −30 dBm input. (**b**) Resultant network, (**c**) PCB layout of the L-matched Delon doubler with adjusted values on FR4 substrate (**d**) Fabricated PCB of the L-network matched Delon voltage doubler.

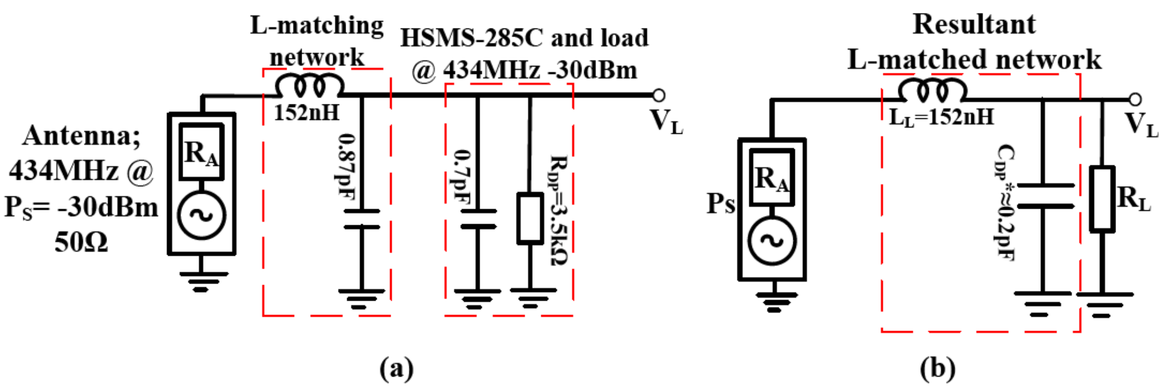
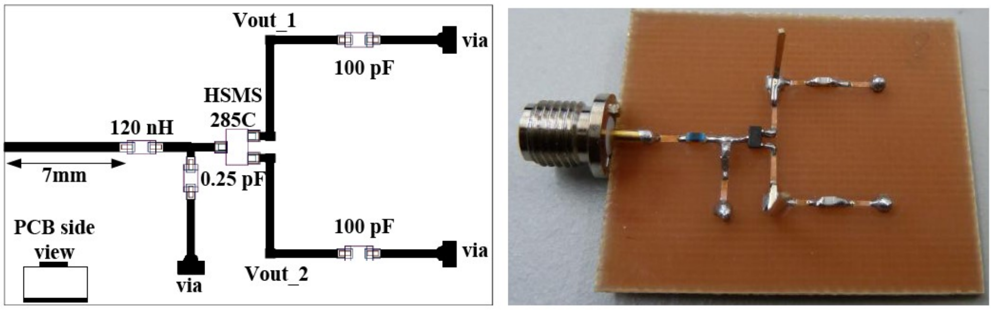


Figure 6. *Cont.*



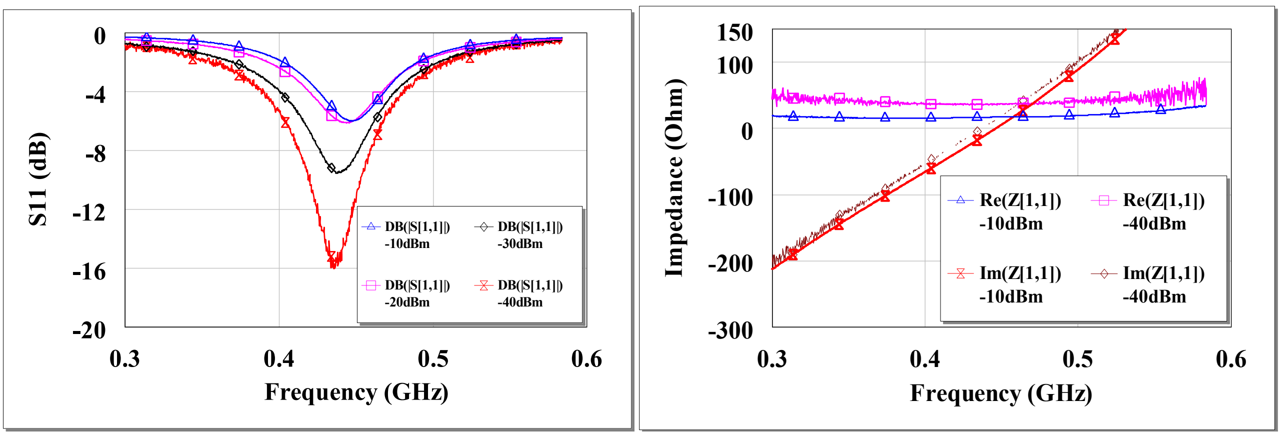
(c) **(d)**

Figure 6(a,b) assume perfect characteristic impedance between the various components in the matched circuit. When a copper route is introduced between components and on a material substrate, it must be accounted for in the total impedance as seen by the source or load. This PCB impedance compensation is carried out in Advance Design Systems (ADS) from Agilent [36]. ADS has extensive models for microstrip substrates to account for its impedances. The optimized layout using ADS microstrip models and its compensated values in the passive tuning components for a Delon doubler is shown in Figure 6(c).

The circuit reflection coefficient (S_{11}) and input impedance at open circuit are shown in Figure 7. There is high return loss and resonance around 434 MHz. The circuit input impedance at open circuit conditions is ~38 Ω at resonance for −40 dBm and ~17 Ω at −10 dBm input.

The measured L-matched circuit efficiency and voltage sensitivity is shown in Figure 8. The maximum measured L-matched efficiency at −30 dBm is 22% at ~20 kΩ load and an open circuit voltage of 124 mV. At −10 dBm, the maximum efficiency and open circuit voltage is 47% and 2 V respectively. At the optimal load of ~20 kΩ, the detected voltage is 58 mV and 1 V at −30 dBm and −10 dBm respectively.

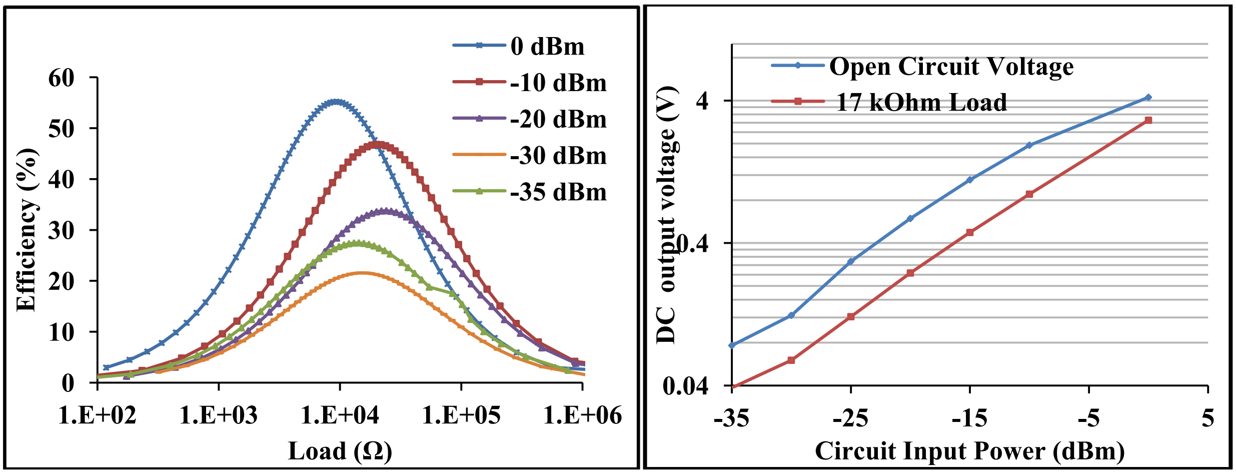
Figure 7. Measured open circuit S_{11} of the L-matched Delon circuit at different input power levels from a 50 Ω source (**left**), measured open circuit input impedance at −10 dBm and −40 dBm of the L-matched circuit (**right**).



The open circuit voltage gain is 25 at −30 dBm and 40 at −10 dBm. The maximum measured efficiency at −35 dBm is 27%. This is higher than that of −30 dBm due to the better matched circuit

impedance at −35 dBm (35 Ω) than at −30 dBm (27 Ω) input. The L-matched RF to DC power converter has a loaded *Q*, sensitivity and efficiency determined mainly by the diodes resistance, diodes junction potential, connected resistance and antenna source resistance at matched conditions.

Figure 8. Measured L-matched circuit efficiency *versus* resistive load at various input power levels at 434 MHz (**left**), measured open circuit voltage and at 17 kΩ load *versus* input power at 434 MHz (**right**).



2.5.4. PI-match RF to DC Power Converter

A highly selective or small frequency bandwidth RF power converter is realized with a PI-network in-between the source impedance from the antenna and the diode rectifier. A PI-network is a 'back to back' L-network that are both configured to match the load and source impedance to an invisible resistance located at the junction between the two L-networks [37]. The quality factor of the L-network with the parallel resistance is given by Equation (26):

$$Q_P^{\ *} = \sqrt{\frac{R_P}{R^*} - 1}, \tag{26}$$

where R_P is the parallel resistance, R^* is a virtual resistance and Q_P^* is the quality factor of the L-network with the parallel resistance. The quality factor of the L-network with the series resistance is given by Equation (27):

$$Q_S^{\ *} = \sqrt{\frac{R_S}{R^*} - 1}, \tag{27}$$

where Q_S^* is the quality factor of the L-network with the series resistance. The unloaded quality factor; Q_S^* or Q_P^* is set higher than what is normally achieved with a single L-network [37] to realize the small frequency bandwidth circuit. The resistance of the load is assigned the parallel network in a PI-matched circuit if its series equivalent resistance is higher than the source series equivalent resistance; the opposite is true if the source is higher than the load. Equation (26) and Equation (27) are synonymous to Equation (8), except the lowest resistive impedance in Equation (8) is substituted with the virtual resistance which is dependent on the newly desired circuit selectivity. From Equations (26) and (27) the loaded quality factor of the PI-matched circuit can be written as Equation (34) in terms of Q_S^* and Q_P^*:

$$Q^2 = \left[\left(\frac{Q_P^{*2}+1}{Q_S^{*2}+1}\right)-1\right], \tag{28}$$

where Q is the loaded quality factor of the PI-network. Q_S* or Q_P* are the unloaded quality factors of the PI-matched network. The larger value among the unloaded quality factors result in small frequency bandwidth response which is desired when matching a source and load impedance with a PI-network. Some authors approximate the highest value of Q_S* or Q_P* or their algebraic sum as the loaded quality factor of the PI-network as in [35] and [37], but Equation (28) gives the exact loaded Q of the PI-matched circuit in terms Q_S* and Q_P*. This allows for the correct estimation of the maximum voltage gain from the loaded quality factor.

2.5.5. Selectivity RF to DC Converter Generalized Analytical Model

An example of a PI-matched RF to DC converter using the HSMS-285C diodes operating at 434 MHz for −30 dBm input is presented first and then the generalized model is discussed. The circuit is matched for Q_P* of 60 between the antenna and the resistance of the diodes as shown in Figure 9.

Figure 9. Impedance diagram of PI-matched RF power converter; (**a**) Impedance diagram of 50 Ω source and the HSMS-285C diodes at 434 MHz, (**b**) Resultant PI matched network between the antenna source and load resistance.

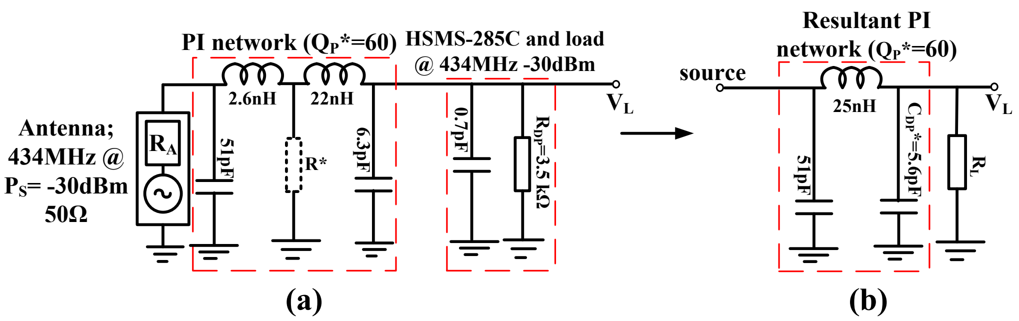
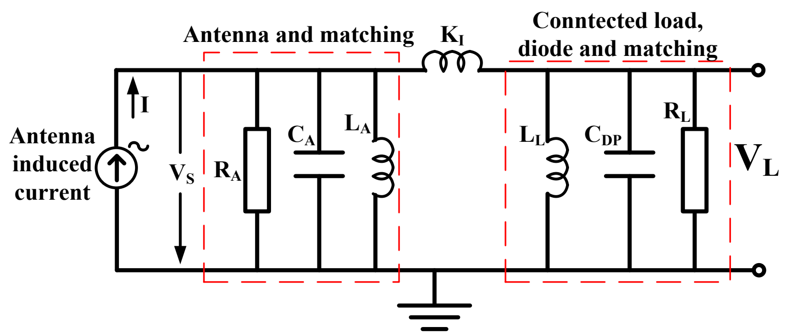


Figure 9(b) can also be modeled as an inductive coupling of two parallel RC circuits. A more general look at such a circuit is shown in Figure 10, as an inductive coupling of two parallel RLC resonators with a current source.

Figure 10. Inductive coupled parallel RLC small signal model of a generalized PI-matched antenna and diode rectifier.



The first parallel RLC resonator is modeled as impedance from the antenna and some passive matching components. The second parallel RLC resonator is modeled as impedance from the linearized diodes, its connected load and some passive matching components. I is the antenna induced current, V_S this time is the voltage across the parallel R_A and K_1 is the coupling element between the two parallel resonators. Using Kirchoff's current laws, the node equations can be expressed as Equations (29) and (30):

$$I = V_S\left[\frac{1}{R_A} + j\omega C_A - \frac{j}{\omega L_A} - \frac{j}{\omega K_1}\right] + \frac{jV_L}{\omega K_1} \tag{29}$$

$$0 = \frac{jV_S}{\omega K_1} + V_L\left[\frac{1}{R_L} + j\omega C_{DP} - \frac{j}{\omega L_L} - \frac{j}{\omega K_1}\right] \tag{30}$$

Load voltage (V_L) and the source voltage (V_S) at resonance are given by the equations in Equation (31). The resonance frequencies are given by Equation (32):

$$V_L = \frac{\dfrac{-jI}{\omega K_1}}{\left[\dfrac{1}{R_A R_L} + \dfrac{1}{\omega^2 K_1^2}\right]} \quad \text{and} \quad V_S = \frac{\dfrac{I}{R_L}}{\left[\dfrac{1}{R_A R_L} + \dfrac{1}{\omega^2 K_1^2}\right]} \tag{31}$$

$$\omega C_A - \frac{1}{\omega}\left\{\frac{1}{L_A} + \frac{1}{K_1}\right\} = 0 \text{ and } \omega C_{DP} - \frac{1}{\omega}\left\{\frac{1}{L_L} + \frac{1}{K_1}\right\} = 0 \tag{32}$$

From V_L and Vs in Equation (31), the voltage gain at resonance can be expressed as:

$$\frac{V_L}{V_S} = \frac{R_L}{j\omega K_1} \tag{33}$$

The maximum of Equation (33) is obtained when:

$$j\omega K_1 \rightarrow 0 \;\; or \;\; R_L \rightarrow \infty \tag{34}$$

Since $j\omega K_1$ is restricted by the conditions in Equation (32) to attain resonance, one cannot manipulate $j\omega K_1$ alone without changing the resonance conditions. What can drive the voltage gain is if R_L is very large at resonance conditions. If the input impedance (V_S/I) of the coupled resonator is maximum at resonance, conditions in Equation (35) hold:

$$\left(\frac{Vs}{I}\right) \rightarrow maximum \;\; when \; \frac{R_L}{\omega^2 K_1^2} \rightarrow 0 \tag{35}$$

Equation (36) may be assumed when $\dfrac{R_L}{\omega^2 K_1^2} \rightarrow 0$:

$$\frac{V_S}{I} = R_A \tag{36}$$

Under these conditions and an optimal coupling coefficient K_{1max}, the maximum voltage gain of the parallel coupled resonator can be written as in Equation (37), where K_{1max} is given by Equation (38):

$$\left|\frac{V_L}{V_S}\right| = \left|V_{gain}\right| = \left|\frac{1}{2}\sqrt{\frac{R_L}{R_A}}\right| \tag{37}$$

$$K_{1(\max)} = \mp \frac{1}{\omega}\sqrt{R_A R_L} \tag{38}$$

The analysis of Section 2.5.2 and parallel coupled RLC resonators show that any antenna and matched rectifying diode can be described as an equivalent circuit of a coupled resonator at a defined operating point. This general model can be applied to optimize other harvesters with complex output impedance such as piezo-harvesters or vibration harvesters for maximum transfer of power or voltage to its connected load. The model can also be applied to near field magnetically coupled antennas/coils for optimization.

2.5.6. Broadband RF to DC power converter

A broadband network is preferred when an RF to DC power converter is to be operated for a wide range of frequencies. A broadband converter is realized by connecting successive L-networks together in a multi-network between the antenna source and the rectifying diodes. The result is broadband or multiband RF power converter around certain frequencies. This can be deduced from the general model of a coupled resonators that by choosing certain passive components between a source and the load, it is possible to have more frequencies (ω) fulfilling Equation (32) and hence a result of multiple resonant frequencies or broader bandwidth at match conditions. For a two stage L-connected match, the quality factor of the L-network with the parallel resistance is given by Equation (39):

$$Q_P^{\ *} = \sqrt{\frac{R_P}{R^*} - 1} \tag{39}$$

The quality factor of the L-network with the series resistance is given by Equation (40):

$$Q_S^{\ *} = \sqrt{\frac{R_*}{R_S} - 1} \tag{40}$$

From Equations (39) and (40) the loaded quality factor of the two stage L-connected broadband network may be written as Equation (41) in terms of the unloaded quality factors; Q_S* and Q_P*:

$$Q^2 = \{(Q_P^{*2} + 1)(Q_S^{*2} + 1)\} - 1 \tag{41}$$

R* in this case may be chosen if it is larger than R_S and lower than the R_P. The highest possible bandwidth between a resistive source and resistive load is found for a virtual resistance (R*) given in Equation (42) [37]:

$$R^* = \sqrt{R_S R_P} \tag{42}$$

For complex loads such as rectifying diodes or transistors, the largest achievable bandwidth prescribed by Equation (42) is limited by the load or source component quality factor, since Equation (42) does not take into account reactive impedance associated with the source or load.

2.5.7. Broadband-Match RF to DC Converter Results and Discussion

The antenna source resistance was broadband matched to the HSMS-285C diodes (and load) resistance at −30 dBm input around 434 MHz. For a desired Q_P* and Q_S* of 2.7 there is ~0.4 pF inherent diode capacitance which is un-tuned using a two stage L-matching network [Figure 11(b)]. This is because the HSMS-285C diodes provides an inherent component quality factor of 6.96 at 434 MHz for −30 dBm input, hence a broadband circuit with Q_P* lower than this inherent component quality factor of the diodes (and load) is difficult to achieve without trade-offs. However, connected L-networks with Q_P* as high as the diode component quality factor may perform worse than a single L-matched network with similar loaded quality factor. This is due to redundant components of the connected L-networks which have inherent losses.

Figure 11. Impedance diagram of broadband RF power converter; (**a**) Broadband match around 434 MHz with loaded Q of 2.7, (**b**) Resultant impedance matching network with un-turned capacitance of 0.4 pF.

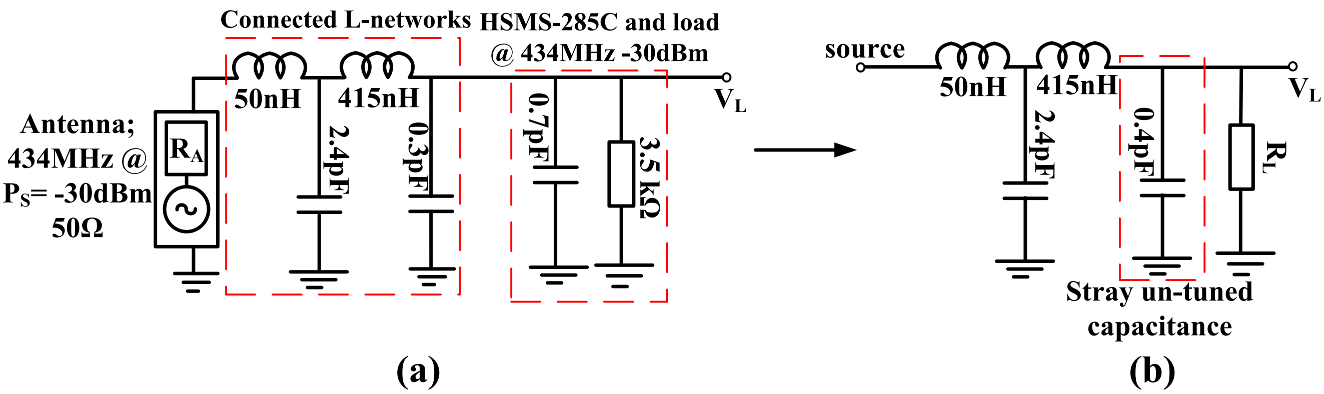
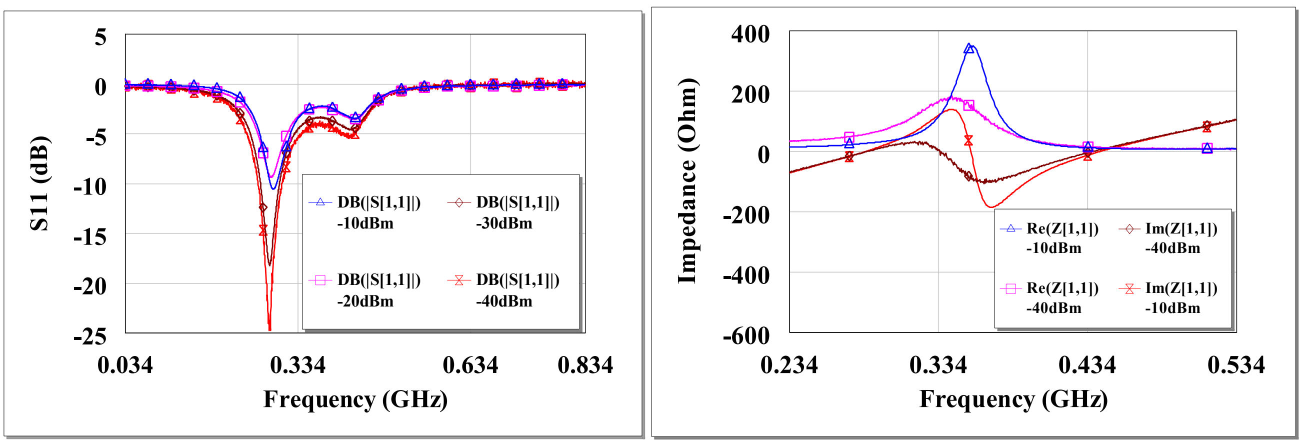


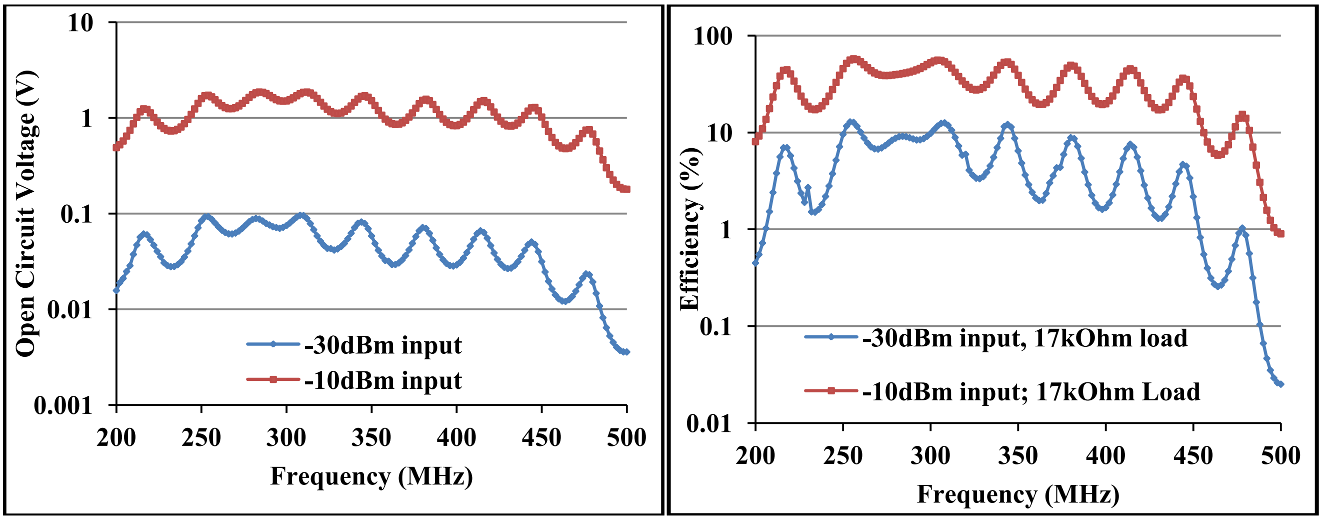
Figure 12. Measured open circuit S_{11} of the broadband circuit around 434 MHz at different input power levels from a 50 Ω source (**left**), measured open circuit input impedance at −10 dBm and −40 dBm of the broadband circuit (**right**).



Therefore the broadband circuit is matched for Q_P* of 2.7, notwithstanding the un-tuned shunt capacitance as can be seen in Figure 11(b). Figure 12 shows the circuit S_{11} at various input power levels and input impedance at open circuit conditions. From Figure 12 (left) there is ~−5 dB return loss

from 200 MHz to 500 MHz providing an operating band of ~300 MHz. The impedance of the circuit shows resonances at ~290 MHz and ~450 MHz as shown in Figure 12(right). A third resonance occurs around 356 MHz at −10 dBm as the frequency of highest harvester input resistance (~350 Ω) and where the reactive impedances approach their extremes. Figure 12 show that a wireless EM harvester can exhibit different resonance scenarios depending on the dominant instantaneous conditions. The efficiency and voltage sensitivity of the broadband matched wireless EM harvester are shown in Figure 13. The average open circuit voltage is 47 mV and 1.1 V at −30 dBm and −10 dBm, respectively, when operating from 200 MHz to 500 MHz.

Figure 13. Measured open circuit voltage *versus* frequency sweep from 200 MHz to 500 MHz for −10 dBm and −30 dBm (**left**), measured efficiency at 17 kΩ load *versus* frequency sweep for −10 dBm and −30 dBm (**right**).



The broadband circuit achieves average efficiency of 5% at 17 kΩ load for −30 dBm and 30% at 17 kΩ load for −10 dBm input power from 200 MHz to 500 MHz. Figure 13 further confirm a direct link between frequency response and the unloaded quality factors. For Q_S* and Q_P* of ~2.7, the circuit response is broadband around 434 MHz.

2.6. High Voltage Sensitive RF to DC Converter

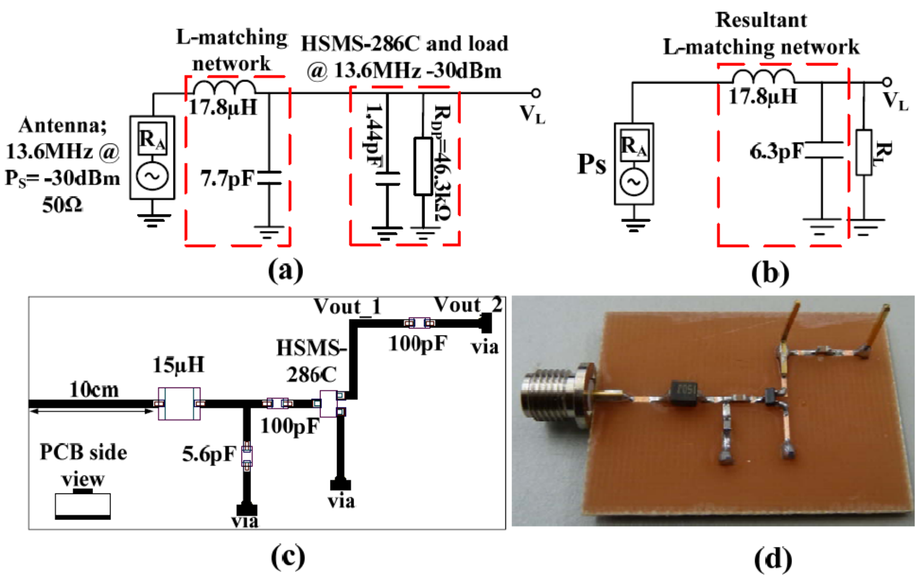
The current state of the art low power remote sensors would require a DC voltage supply of about 1 V and DC current of about 30 μA for operation. Therefore, the issue is not only how efficient a wireless EM harvester is in converting RF to DC power, but also what the output DC voltage and current of the EM harvester are at the RF input power level [38]. Equations (11,24) and (33) show that the maximum voltage sensitivity of a coupled resonator system or an RF to DC power converter is mostly related to the load and the source resistances at resonance. Therefore high voltage sensitive wireless EM harvester can be achieved with a diode voltage doubler with a very high input resistance relative to the antenna source without the need to cascade the diodes as in voltage multipliers. If the diodes been used for the RF to DC power conversion cannot provide high resistive impedance at the working frequency relative to the antenna source, then a DC-DC converter can be applied after the EM harvester as presented in [39] or the diodes may be cascaded by way of multipliers as presented in our

earlier work [40] and by several other authors [3,5,14]. In case of multipliers, the input voltage ought to be high enough to overcome the junction potential of the several diodes in the multiplier network. If frequency is not a constraint, then a frequency sweep *versus* impedance for the diodes can be made and the frequency where the diodes exhibits high resistive impedance can be used to realize high voltage sensitive wireless RF harvester. For Schottky diodes, high resistive impedance occurs mostly at lower frequencies (see Figure 3). The measured voltage gain of a high resistive diode pair (voltage doubler) is presented in the next results.

2.6.1. High Voltage Sensitive RF to DC Converter Results and Discussion

The presented result was L-matched using 50 Ω resistance of the antenna source and the resistance of the HSMS-286C diodes (and load). The HSMS-286C diodes do provide high resistive impedance at low frequencies; notwithstanding the flicker noise which causes its resistive (and reactive) impedance to fluctuate. The HSMS-286C has low forward junction potential (~350 mV at 1 mA) per diode and series impedance of ~1.5–j8.1 kΩ or parallel impedance of ~$-j8.3(46.3)/(-j8.3 + 46.3)$ kΩ at 13.6 MHz for −30 dBm input. Even though the HSMS-286C diodes unloaded component quality factor at 13.6 MHz is similar to that of the HSMS-285C diodes at 434 MHz, the elevated resistive impedance at 13.6 MHz fulfills the condition for high voltage sensitivity relative to a 50 Ω antenna source at resonance conditions.

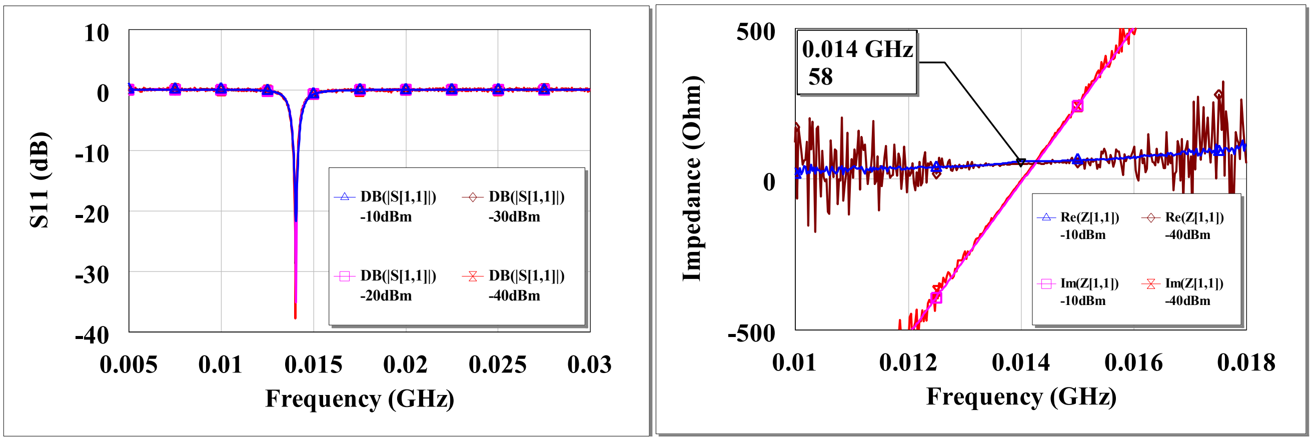
Figure 14. (**a**) L-matched impedance diagram for matching the HSMS-286C diodes at 13.6 MHz at -30 dBm input. (**b**) Resultant network, (**c**) PCB layout of the L-matched Greinacher doubler with adjusted values due to impedances provided by copper route on FR4 substrate with thickness of 1 mm. (**d**) Fabricated PCB of the L-matched RF to DC power converter.



The high voltage sensitive EM harvester operating at 13.6 MHz is as shown in Figure 14. On the realized PCB is a Greinacher doubler. An inductance of 15 μH and a shunt capacitance of 5.6 pF were the adjusted values after the microstrip contributions.

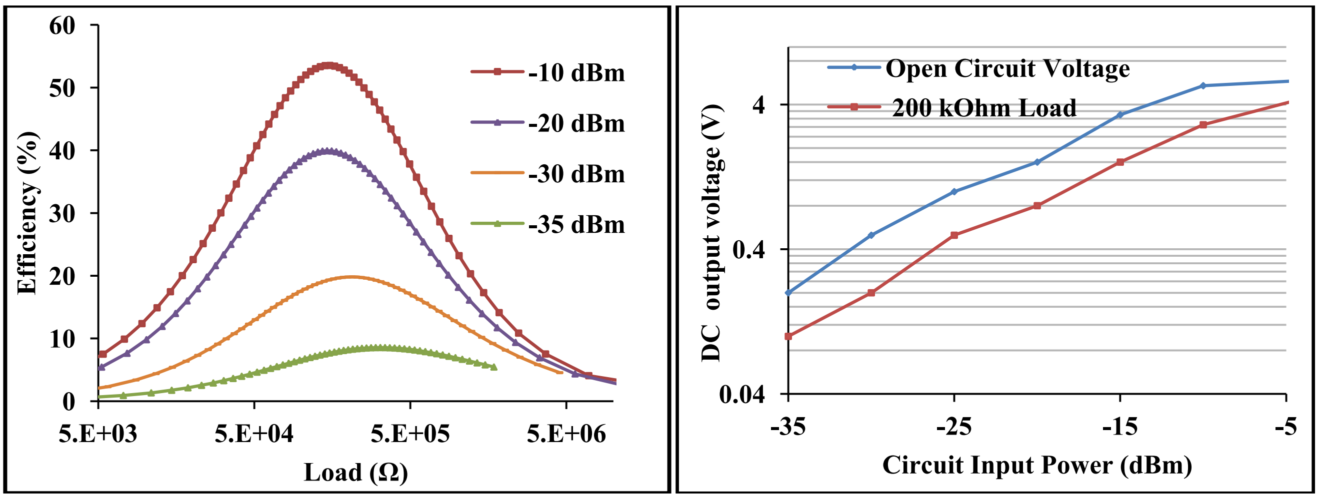
The measured S_{11} and input impedance at open circuit are shown in Figure 15. There is high return loss and resonance around 13.6 MHz. The circuit input impedance at open circuit conditions is 58 Ω at resonance for both −40 dBm and −10 dBm.

Figure 15. Measured open circuit S_{11} of the L-matched HSMS-286C diodes at 13.6 MHz for different input power levels from a 50 Ω source (**left**), measured open circuit input impedance at −10 dBm and −40 dBm of the L-matched HSMS-286C diode at 13.6 MHz (**right**).



The efficiency and voltage sensitivity of the high voltage sensitive wireless EM harvester are shown in Figure 16.

Figure 16. Measured circuit efficiency *versus* load at various input power levels at 13.6 MHz (**left**), measured open circuit voltage and at 200 kΩ load *versus* input power at 13.6 MHz (**right**).



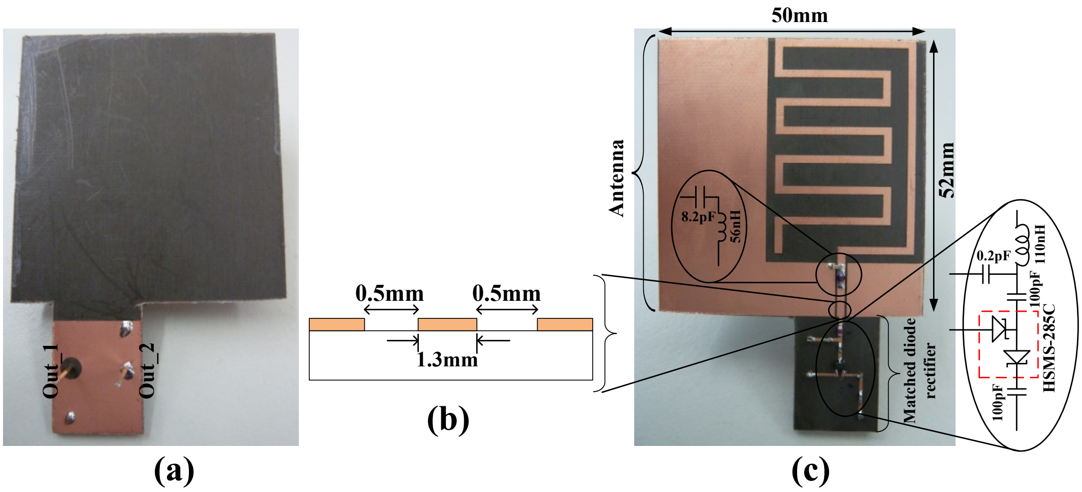
The maximum measured efficiency at −30 dBm is 20% for ~200 kΩ load and an open circuit voltage of 0.5 V. At −10 dBm, the maximum efficiency and open circuit voltage are 54% and 5.4 V respectively. At the optimal load of ~200 kΩ, the detected voltage is 0.2 V and 2.9 V at −30 dBm and −10 dBm respectively. The open circuit voltage gain is 100 at −30 dBm and 108 at −10 dBm.

Even though the RF to DC converter presented in Section 2.5.3 is the same as the L-match circuit realized with the HMSM-286C diodes at 13.6 MHz, the voltage gain is increased by a factor of 4 due to the large difference between the diodes (and load) resistance and source resistance so that at matched conditions high voltage gain occurs. The loaded *Q* of the L-matched circuit is 30 which results in small frequency bandwidth just like a PI-matched diode rectifier presented in our earlier work [40]. From this result and the results from our earlier presented PI-matched EM harvester, it can be inferred that all high loaded *Q* RF to DC circuits have high selectivity but not all highly selective RF to DC circuits have high loaded *Q*. The voltage sensitivity of the matched HSMS-286C diode at 13.6 MHz can be improved if its resistive impedance is not lowered by the flicker noise.

3. Wireless EM Power Harvester

A wireless EM harvester, consisting of a rectifying antenna (*rectenna*) was designed to find a compromise between size and performance of its antenna. The rectenna is shown in Figure 17.

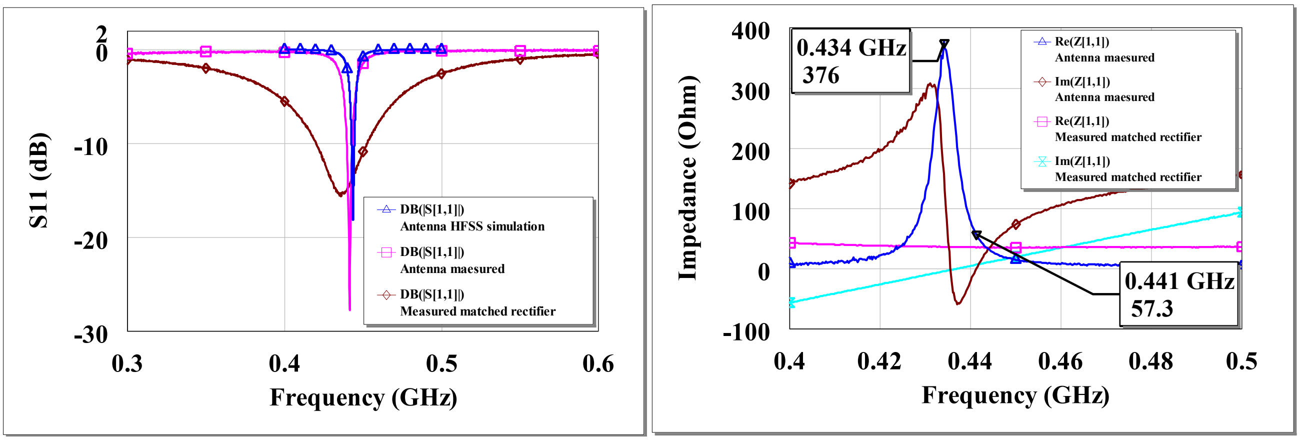
Figure 17. Rectenna realized on a Duroid 5880, 1.57 mm substrate. (**a**) Backside of the rectenna, (**b**) cross-section of antenna output coplanar stripline dimensions (**c**) frontside of the rectenna.



The antenna (planar) part of the rectenna is based on our earlier work [41]. In contrast to the earlier presented antenna, this rectenna is realized on a Duroid [42] substrate of thickness 1.57 mm. Duroid 5880 has lower loss tangent of 0.0004 at 1 MHz compared to 0.025 at 1 MHz for FR4. This means there is less loss in the transmission of signals on a Duroid PCB at this frequency range. The antenna part is fabricated to resonate around 434 MHz; hence its dimensions of 5 × 5.2 cm make it electrically small. The antenna is tuned with a chip inductor and a capacitor to achieve the resonance frequency around 434 MHz [Figure 17(c)]. This is done at a cost of reduced antenna radiation efficiency. An antenna is one of the few components the size of which is related to the operating frequency. Thus, if the size of an antenna is fixed, resonance frequency reduction of the antenna can only be achieved with penalty factors [10]. The antenna's output impedance is tuned with the dimensions of the coplanar stripline as shown in Figure 17(b).

HFSS [43] was used to simulate the presented antenna and to find the correct capacitive and inductive components for frequency tuning before the optimized design was fabricated. The simulated antenna resonances occur at 438 MHz and 445 MHz. At these frequencies, the radiation efficiency is 20% and a peak gain of −6 dBi. The rectifying part of the rectenna consists of L-matched HSMS-285C diodes (Figure 17(c)). The L-matched HSMS-285C part of the rectenna can be engineered to be as small as possible if required. The separate parts of the rectenna were characterized by terminating their ends and measuring the individual reflection coefficients just like the power converters presented in Section 2. Figure 18 shows the measured antenna and matched rectifier individual S_{11} and impedance. Figure 18 (left) also show the HFSS simulated S_{11} results. From Figure 18 (right), the measured antenna resonance where the input impedance is at maximum is ~434 MHz. At ~434 MHz, the antenna input resistance is 376 Ω and the reactive impedances approach their extreme (*so called anti-resonance*). The other resonance occurs when the input resistance is 'finite' and the reactive impedance is zero; at ~441 MHz. The input resistance is 57 Ω at ~441 MHz. The rectifier circuit is matched for the antenna's resistance at ~441 MHz.

Figure 18. Antenna HFSS simulated, antenna measured, and measured L-matched diode rectifier S_{11} on a Duroid 5880 PCB for −30 dBm input (**left**), Measured open circuit input impedance of antenna and rectifier at −30 dBm input (**right**).



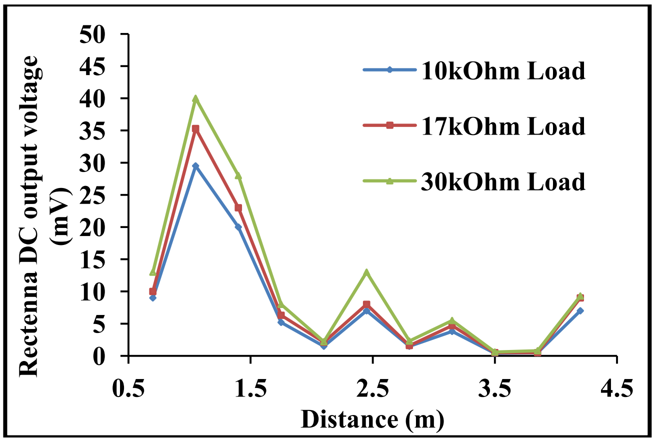
3.1. EM Range Results and Discussion

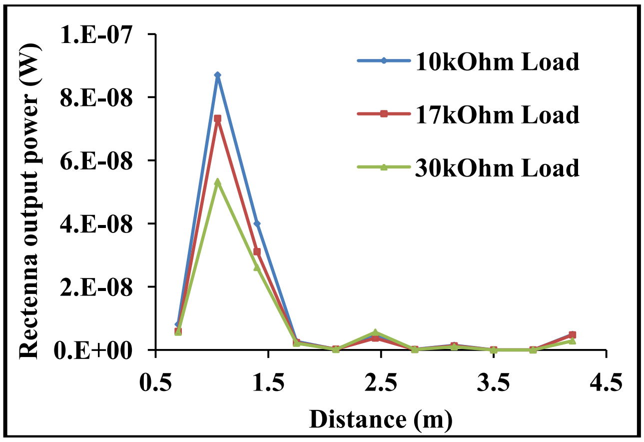
At far field between wireless EM transmitting and receiving antenna, the coupling mechanism between the transmitting and receiving antenna is neither capacitive nor inductive as is the case for the RF to DC converters. The coupling is radiative which can be described by the Friis equation of transmission on the assumption that the transmitting and receiving antenna are in free space [44]. A modified Friis equation for a transmitting and receiving antenna at far-field (R >> λ and R >> transmitting antenna largest dimension) to each other at a specified direction is given by Equation (43) [45]. Equation (43) assumes real world open space conditions:

$$\frac{P_r}{P_t} = F_{envt} G_t G_r \left(\frac{\lambda}{4\pi R} \right)^2, \tag{43}$$

where *Pr* is the power at the receiving antenna port, *Pt* is the power supplied at the transmitting antenna port, F_{envt} is a factor accounting for environmental effects as such ground reflections among others, *Gt and Gr* are the transmitting and receiving antenna gain (*at specified direction*) respectively. *R* is the distance between the transmitting and receiving antenna and λ is the wavelength of the transmitting EM wave. The rectenna receiving range measurements were carried out in an open space (*hall*) with the antennas 2 m above ground level. The transmitting and receiving antennas were arranged in the direction of their peak gain. The rectenna range performance is shown in Figure 19. According to Equation (43), the efficiency of RF power transferred between a sending and receiving antenna depends on controllable factors like the gain of the antennas in the arranged direction and the radiation efficiency of the antennas. Since the receiving/transmitting antenna's incorporated in remote harvesters for sensor powering are normally small in relation to their operating frequencies, they tend to be less efficient.

Figure 19. Rectenna receiving range performance by sending 17 dBm (50 mW) at a gain of −6 dBi at 437 MHz. Output DC voltage *versus* receiving distance for different loads (**left**), loads output power *versus* receiving distance (**right**).





The efficiency of the rectenna's antenna is ~20% at resonance. A 'perfectly' matched RF to DC power converter operating in its square law region has efficiencies in the region of 20% as depicted in Section 2. The transmitting antenna was the same as the antenna incorporated in the rectenna. By transmitting the EM power with a small antenna (5 cm × 5.2 cm) at 437 MHz with efficiency of ~20% and at a gain of −6 dBi, the power delivered by the rectenna is generally low at far-field from the transmitter as can be seen in Figure 19. A mediocre transmitting antenna was used to transmit the EM waves due to limitations in the European Union about transmitting EM power at certain frequencies; so the goal in the rectenna range experiment is to show the lowest limit functionality of such a harvester. At 4.2 m from the electrically small transmitting antenna transmitting at 17 dBm, the rectenna harvested DC voltage and power are 9 mV and 5 nW respectively for 10 kΩ load. It can be seen from Figure 19 that the harvested voltage/power generally degrades as an inverse square of distance from transmitter as described by Friis equation. The measured received power however alternate along this R^{-2} fit as shown in Figure 19. This anomaly is accounted for by F_{envt} [Equation (43)] as influence of ground reflections and polarization in real world open field measurements [45]. For any particular distance *R*, the signals reflected from ground can be constructive with the direct signal to the rectenna,

in which case the measured power may be higher than that predicted by the original Friss equation as in [44]. The ground effect can also be destructive, in which case the measured power will be lower than what is predicted by the original Friis equation.

4. Conclusions

Optimization of Schottky diode-based RF to DC power converters using different matching techniques for wireless EM energy harvesting applications is presented. Using scattering parameters for small signal modeling, it is shown that wireless EM harvesters can be generally described as coupled resonators with efficiencies and maximum voltage sensitivity depending mostly on the source and load resistances under matched conditions. The analytical models allow systematic control in the design of passive wireless EM harvesters. Based on these analyses, a rectenna is built and tested for lower limit functionality from harvesting ambient EM waves. The analysis presented in this work may also be applied to optimize derivatives of wireless EM harvesters like RFID tags, NFC, wireless chargers *etc.*, for efficient powering of their sensors or integrated circuits. Generally, most energy harvesters and their matched loads can be described as coupled resonators and thus may be optimized with the methods presented in this work.

Acknowledgments

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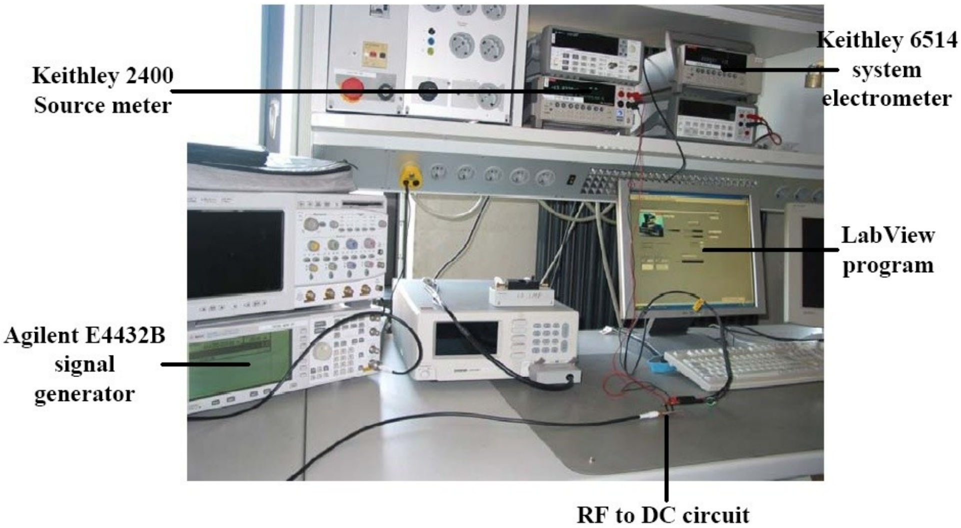
Appendix A: Measuring Setup for RF Rectifier Efficiency and Voltage Sensitivity

The measuring setup is as shown in Figure A1.

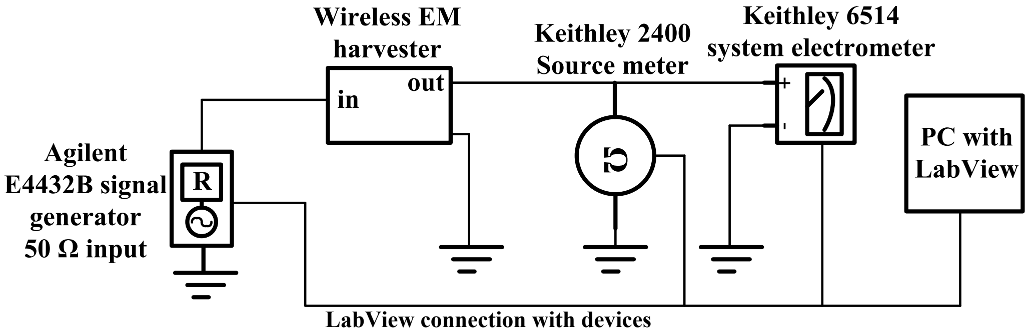
Figure A1. RF to DC Power converter characterization setup.



The RF to DC circuit efficiency and voltage sensitivity measurements were made with a Keithley 2400 source meter and Keithley 6514 system electrometer with an Agilent E4432B signal generator providing 50 Ω RF signal into the circuit board.

The closed circuit current drawn by the RF to DC power converter (*without load*) from the generator is first determined by the Keithley 2400 source meter; then starting from this current, the value of the current is decreased at set intervals to creates virtual load resistances to the circuit for up to a lowest current of 0.1 µA. The 6514 system electrometer is used to measure the output voltage. The number of data point is set through LabView [46] as well as the measurements. Additionally open circuit voltage or at specific loads and frequency sweep can be made through the LabView program. At −40 dBm input power and below, the detected voltages and currents were difficult to measure accurately with the measuring setup; hence measurements were made up to a minimum of -35 dBm input power. The circuit layout for the efficiency and voltage sensitivity measurements is schematically shown in Figure A2.

Figure A2. RF to DC power converter characterization circuit.



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Optimization of Passive Low Power Wireless Electromagnetic Energy Harvesters

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Abstract: This work presents the optimization of antenna captured low power radio frequency (RF) to direct current (DC) power converters using Schottky diodes for powering remote wireless sensors. Linearized models using scattering parameters show that an antenna and a matched diode rectifier can be described as a form of coupled resonator with different individual resonator properties. The analytical models show that the maximum voltage gain of the coupled resonators is mainly related to the antenna, diode and load (*remote sensor*) resistances at matched conditions or resonance. The analytical models were verified with experimental results. Different passive wireless RF power harvesters offering high selectivity, broadband response and high voltage sensitivity are presented. Measured results show that with an optimal resistance of antenna and diode, it is possible to achieve high RF to DC voltage sensitivity of 0.5 V and efficiency of 20% at −30 dBm antenna input power. Additionally, a wireless harvester (*rectenna*) is built and tested for receiving range performance.

Keywords: RF energy harvesting; wireless power transmission; coupled resonators; Schottky diode; RF to DC power converter; impedance matching; PI-matching; L-matching; rectenna

1. Introduction

For autonomous powering of sensor nodes in remote or inaccessible areas, wireless power transfer provides the only viable option to power them from an energy source. Due to the low power density of ambient RF at far-field from transmitters, there is a need to optimize each aspect of a wireless RF energy harvester for possible realistic applications. Today remote autonomous sensors are mostly powered by batteries, which have limited lifespan. Renewable powering has the potential to power autonomous sensors perpetually. Due to the expansion of telecommunications technology ambient electromagnetic (EM) power is among the most common sources of ambient energy. There are power transmitters/receivers scattered in practically any society, ranging from television transmission stations to cell phone transmitters and even wireless routers in our homes/offices or mobile phones. These transmitters in our environment and others which are on special dedicated frequencies produce ambient RF power (on the order of microwatts) which can be used as a source for powering remote microwatt budget sensors through wireless energy harvesting. This work presents different matching techniques based on different application requirements using Schottky diode-based RF to DC power converting circuits for wireless remote EM energy harvesting around 434 MHz and 13.6 MHz. Generalized analytical models and limitations of the matched RF to DC power converters are discussed. A wireless RF energy harvester consisting of an antenna and a matched diode rectifier is then realized and its performance tested. Passive wireless energy harvesting also finds applications in near field communications (NFC) [1], RFID tags [2–5], implantable electronics [6,7], and environmental monitoring [8], among others.

1.1. State of the Art

Hertz was the first to demonstrate the propagation of EM waves in free space and to demonstrate other properties of EM waves such as reflection using parabolic reflectors [9]. Wireless power transmission was then investigated and demonstrated for possible wireless remote powering by Tesla. Electromagnetic power beaming for far field wireless power transfer using collimated EM waves was proposed in the 1950s [9]. Recent advances in ultralow power sensors means ambient omni-directional EM power can be used as a source for powering remote sensors without the need to collimate the EM power through the wireless space. Mickle [10] and McSpadden [11] have presented earlier work on wireless energy harvesting systems using Schottky diodes and rectennas where the usability of ambient RF power into DC power was shown. Sample [12] presented a wireless harvester which can harvest EM power from TV and radio base stations transmitting 960 kW of effective radiated power; 60 μW was harvested at a range of about 4 km. Umeda [13] and Le [14] have presented more integrated wireless energy harvesters based on CMOS RF to DC rectifying circuits. CMOS-based rectifying power converters provide full compatibility with standard CMOS technologies and have advantages in batch processes for mass production. The drawback of CMOS-based diode connected transistors is the need to bias the gate of the transistors for the rectifying circuits to effectively function. This gate bias is provided externally, which makes the system not passive. Without the injection of external charges or a biasing of the transistor gate, the circuit has low efficiency, especially when the amplitude of the input voltage is low [15]. Shameli [2] presented a passive CMOS RF to DC power converter with a

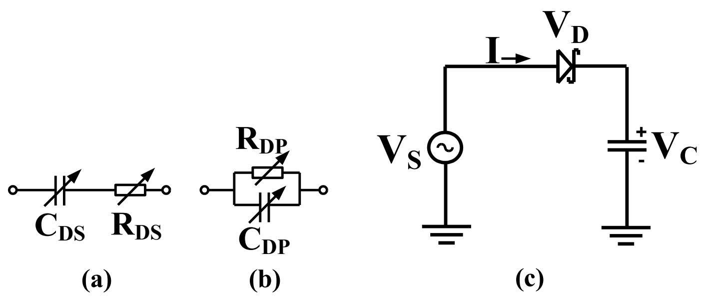
voltage sensitivity of 1 V at −14.1 dBm input, but the circuit efficiency was only 5 %. Zbitou [16] presented an RF to DC converter based on Schottky diodes and achieved 68 % efficiency at 20 dBm RF input power. Ungan [17,18] presented antennas and high quality factor RF to DC power converters at 24 MHz and 300 MHz for RF wireless energy harvesting at -30 dBm input power. The power converter used high quality factor resonators for impedance matching the EM source and the diodes and achieved high open circuit voltage sensitivity of 1 V/μW. Boquete [19] presented a risk assessment system for calculating insurance premiums by monitoring mobile phone usage while driving. This was done by harvesting EM power from detected mobile phone usage during driving for risk assessment. Heikkinen [20] presented rectennas on different substrates at 2.4 GHz using transmisson lines to match the antennas output resistance (*at resonance*) to the rectifying diodes. Akkermans [21] presented a rectenna design by complex conjugating impedance provided by a microstrip structure to a diode so that resonance may be achieved for a working frequency. This design approach may need sophisticated tools to realize and the dominant resonance frequency of the rectenna can be unpredictable in practice. Hagerty [22] presented rectenna arrays for broadband ambient EM harvesting and characterized the harvesters from 2 GHz to 18 GHz; rectennas combine impedance matching the RF rectifying circuit and the antenna into one compact device, but an array of rectennas may increase the overall size of an EM harvester. Herb [23] and Vullers [24] have provided a comprehensive state of the art for micro energy harvesting and have explored the various techniques used for harvesting ambient renewable energy.

2. RF to DC Power Converter

2.1. Diode Rectifier

A junction diode equivalent circuit and simple Schottky diode rectifier are shown in Figure 1. R_{DS} is the diode resultant series resistance, C_{DS} is the diode resultant series capacitance, R_{DP} is the diode resultant parallel resistance, C_{DP} is the diode resultant parallel capacitance, Vs is the sinusoidal source voltage and Vc is the voltage across the capacitor.

Figure 1. (**a**) Diode series equivalent model, (**b**) Diode parallel equivalent model, (**c**) Simple diode detector.



The diode capacitive impedance is mainly due to the junction capacitances provided by the metal, its passivation and the semiconductor forming the diode. AC power incident on a forward biased diode input is converted to DC power at the output. The current-voltage behavior of a single metal/semiconductor diode is described by the Richardson equation [25] as in Equation (1):

$$I = I_S\left(e^{\left(qV_D/nKT\right)} - 1\right) \tag{1}$$

where I is the current through the diode, I_S is the saturation current, q is the charge of an electron, V_D is the voltage across the diode, T is the temperature in degrees Kelvin and K is Boltzmann constant. The voltage equation around the loop can be derived from Figure 1(c) and is given in Equation (2):

$$V_D = V_S - V_C \tag{2}$$

Since the same current flows through the diode and the capacitor, one can find the average current through the circuit by integrating Equation (1) over a time period. By substituting Equation (2) into Equation (1), V_C can be expressed in terms of V_S by averaging the diode current to zero. This is given in Equation (3) [26]:

$$V_C = \frac{KT}{q}\ln\left[\vartheta_0\left(\frac{qV_S}{KT}\right)\right], \tag{3}$$

where ϑ_0 is the series expansion of the sinusoidal source voltage. Equation (3) can further be simplified for very small amplitude V_S as Equation (4):

$$V_C \approx \frac{qV_S^2}{4KT} \tag{4}$$

Equation (4) shows that for a small voltage source, the circuit output voltage is proportional to the square of the input sinusoidal voltage; hence it's so-called square law operation. Extensions of this model for voltage multipliers and other input signals are presented in [27] and [28]. Equation (4) further confirms that for low input voltage (power $\leq$ 10 dBm), an impedance matching network between the source and the diode is necessary to improve the detected output voltage and efficiency.

2.2. Impedance Matching

The maximum power transfer theorem states that the highest power is transferred to the load when the source resistance is the same as the load resistance. For systems with both resistive and reactive impedances from source and load, the source and the load impedance should be adjusted in a way that they are the complex conjugate of each other through impedance matching. For the purposes of this work, a 50 Ω resistive source is chosen as reference for load impedance matching. The antenna which captures the ambient RF signals is tuned to provide this source resistance at resonance for the rectifying circuit in a complete EM wireless remote harvester. The load is the resistance of the Schottky diodes and the actual connected resistance (*remote sensor*). The specific type of matching network which can be used for complex conjugation depends on the nature of load or source impedance, the desired RF to DC converter functionality and other factors like circuit size, cost, *etc.* The response of a matched RF to DC power converter depends on the matching network used as well as the source or load component quality factors and impedances.

2.3. Diode Impedance

Schottky diodes HSMS-285C and HSMS-286C from Avago [29,30] are used to build the RF to DC power converters. The HSMS-285× or 286× series diodes can be operated as zero biased with relatively low forward junction potential. This allows for the realization of completely passive RF to DC power converters for wireless energy harvesting. The HSMS-285C or 286C is a pair of series connected Schottky diodes in a SOT-323 package. The impedance of the HSMS-285C and HSMS-286C diodes was first measured so it can be matched to the resistance (50 Ω) of the antenna source. This is done by connecting the input of the diodes to a network analyzer and measuring the scattering parameters. These scattering parameters are then converted to the corresponding impedances. The input impedance of a diode depends mainly on the resistive and capacitive impedance provided by the junction of the diode and its connected load. For a couple of diodes arranged in a package such as the HSMS-285C or 286C, the input impedance is the vector sum of the impedances provided by each diode in the package arrangement, the extra impedance associated with the packaging and the connected load. The diode measuring board is as shown in Figure 2. The diodes were measured at room temperature for an input power of -30 dBm at a diode connected load of 1 MΩ with a 100 pF filter capacitor. For the sake of this work, the input impedance of the diodes will always be referred to at these connected load conditions.

Figure 2. (**left**) Reference circuit layout for measuring diodes input impedance, (**right**) measuring printed circuit board (PCB) for diodes input impedance on 1 mm FR4 substrate.

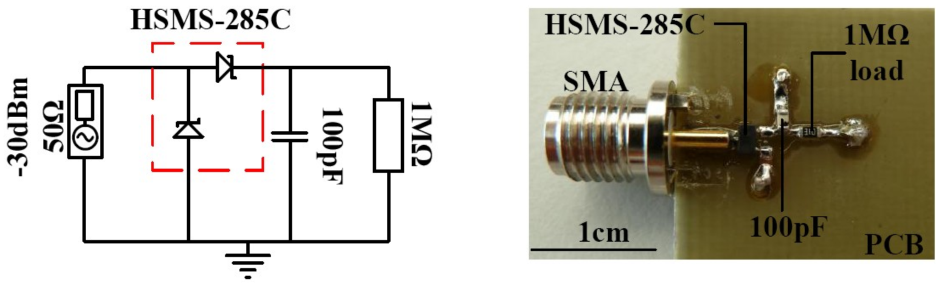
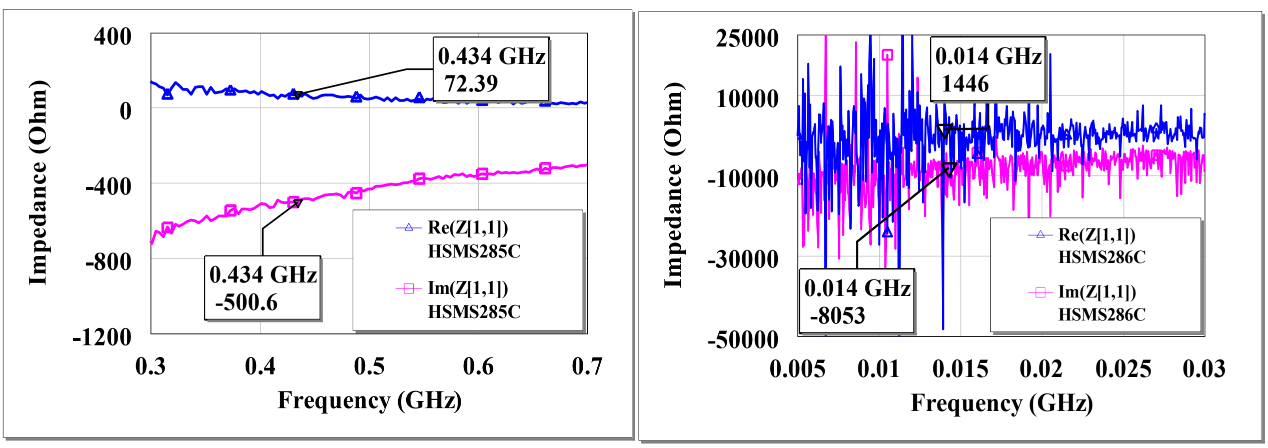


Figure 3. Measured input impedance (Δ resistive, □ capacitive) of HSMS-285C (**left**) and HSMS-286C (**right**) diodes at −30 dBm input with 1 MΩ load and 100 pF filter.



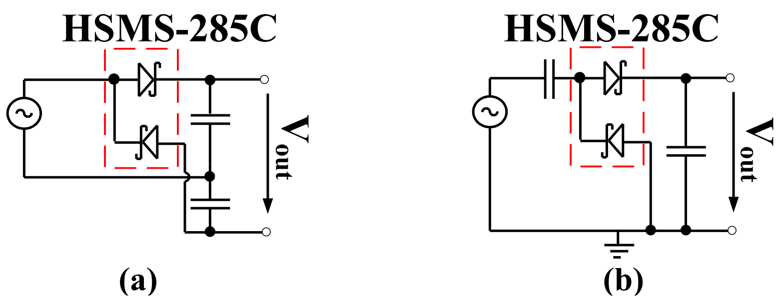
The board is fabricated such that components are soldered directly one into another to prevent additional impedances introduced by copper route. The PCB backside had the ground layer. An example of measured input impedance for HSMS-285C and HSMS-286C is shown in Figure 3.

The diodes quality factor is given by $X_{DS}R_{DS}^{-1}$, where X_{DS} is the resultant series capacitive impedance of the diodes. At an input power of −30 dBm, the measured input impedance of the HSMS-285C diodes is 72–j501 Ω at 434 MHz and 587–j1239 Ω at 13.6 MHz. For HSMS-286C diodes, it is 10–j503 Ω at 434 MHz and ~1.5–j8.1 kΩ at 13.6 MHz for −30 dBm input. The measured impedance of the HSMS-286C diodes at low frequencies (< 60 MHz) shows pronounced fluctuations. The low-frequency excess flicker noise and the shot noise observed in the HSMS-286C have been studied by several authors [31–33]. The pronounced presence of trap states in the depletion region of the semiconductor, mobility fluctuations in carriers, edge effects among other reasons is reported to cause deviations from the ideal Schottky diode behavior and hence generation-recombination noise for some diodes such as the HSMS-286C [34]. When a diode rectifier is matched at a reference operating condition, the matching network may function less effectively at other input power levels, connected load and other operating frequencies. This is due to possible changes in the diode input impedance. Throughout this work the imperfections of the matching circuit at other operating conditions away from the matched reference conditions are accepted without changes to the matching network.

2.4. Voltage Doubler

The Delon voltage doubler and Greinacher doubler are both used to realize the RF to DC power converters presented in this work. The Delon voltage doubler and Greinacher doubler are shown in Figure 4. The diodes output voltage (V_{out}) is doubled what is detected by a simple detector circuit shown in Figure 1. Both doublers produce the same output performance, the only difference is that the Delon doubler has an instantaneous input ground which is not shared with the output.

Figure 4. Circuit diagram of voltage doubler, (**a**) Delon doubler and (**b**) Greinacher doubler.



2.5. Matching Techniques for Antenna Source and RF to DC Power Converter

2.5.1. L-match RF to DC Power Converter

An L-match network converts a source series impedance to its equivalent load parallel impedance or *vice-versa* and tunes out by subtracting or adding any surplus reactance from the load or source with the counter impedance. Series impedance is converted to its parallel equivalent impedance using Equations (5–7):

$$Q_S = \frac{X_S}{R_S} \tag{5}$$

$$Q_P = \frac{R_P}{X_P} \tag{6}$$

where *Xs* is the total series reactive impedance, *Rs* is the total series resistance, R_P is the total parallel resistance, *Xp* is the total parallel reactive impedance, Q_S and *Qp* are the series and parallel quality factors respectively:

$$R_S + jX_S = \frac{R_P \times jX_P}{R_P + jX_P} \tag{7}$$

Equation (7) is the equation of a series sum of impedances and a parallel sum of impedances. It is interesting to note that Q_S and Q_P from an L-matched network may be different from the individual component quality factors as a result of the inherent resistive and reactive impedances in that component. By virtue of Equation (7), Q_S and Q_P must be equal in an L-matched network. Using Equations (5,6) and (7), the ratio of the parallel resistance (*or reactance*) to the series resistance (*or reactance*) can be derived in terms of the quality factors Q_P or Q_S [35]. Since at match conditions, only the resistive impedances dissipate power, the loaded quality factor *Q,* of the L-matched network can be expressed as in Equation (8):

$$R_P = (Q^2 + 1)R_S \tag{8}$$

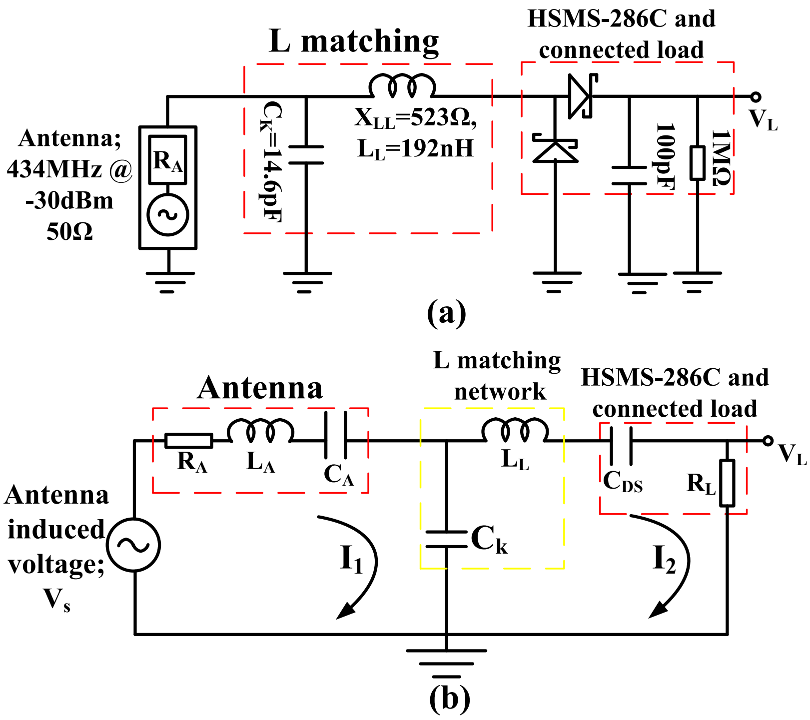
Using Equations (5,6) and (8), series impedance can be converted to its parallel equivalent for a fixed frequency and power level. As an example; a series impedance 72–j501 Ω (HSMS-285C at 434 MHz for −30 dBm input power) is easily converted to $-j510(3519)/(-j510 + 3519)$ Ω as its parallel equivalent with a component quality factor of 6.96. The source resistance is taken as part of the parallel matching network in an L-match circuit if the source series equivalent resistance is greater than the load series equivalent resistance. On the other hand, the load resistance is taken as part of the parallel matching network if the load series equivalent resistance is greater than the source series equivalent resistance. For the purpose of this work, inductors were only used for series impedance matching and capacitors as shunts. This prevents power seeping through any shunt inductor used for impedance matching due the short circuit provided by a shunt inductor to ground and resulting in less output efficiency. Resistors were not used for impedance matching.

2.5.2. L-match RF to DC Converter Generalized Analytical Model

The classical matching technique using Equations (5,6) and (8) is first used to L-match the 50 Ω resistance of the antenna to the resistance of the HSMS-286C diodes (and load) at 434 MHz for −30 dBm input and then the generalized model is discussed. The antenna source resistance was L-matched to the resistance of the diodes (and load). The 50 Ω resistance of the antenna is taken as the parallel matching component and the diodes 10 Ω resistance is the series matching component. The loaded *Q* is found as 2 between the 50 Ω antenna source resistance and the 10 Ω diode series resistance using Equation (8). From this loaded *Q*, a shunt capacitive impedance of 25 Ω (14.6 pF at 434 MHz) using Equation (6) and a series inductive impedance of 20 Ω (7.3 nH at 434 MHz) using Equation (5)

will match the 50 Ω source to the 10 Ω HSMS-286C diodes (and load) series resistance at −30 dBm input. Since the HSMS-286C diodes inherently provides 503 Ω series capacitive impedance at −30 dBm, a resultant series inductive impedance of 523 Ω (192 nH at 434 MHz) is needed to tune the 50 Ω resistive source to the complete HSMS-286C diodes impedance at 434 MHz for −30 dBm input. The L-matched HSMS-286C diodes rectifier is as shown in Figure 5(a).

Figure 5. (**a**) L-match RF to DC harvester using the HSMS-286C diodes at 434 MHz for −30 dBm input. (**b**) Small signal impedance model of a generalized L-matched RF to DC power converter as capacitive coupled series RLC resonator with different resonator elements.



C_K is the tuning capacitance, L_L is the tuning inductance, X_{LL} is the tuning inductive impedance, C_{DS} is the diodes series capacitance, X_{DS} is the diodes series capacitive impedance, V_S is the antenna captured ambient EM voltage, R_A is the resistance of antenna, L_A is the inductance of antenna, C_A is the capacitance of antenna, R_L is the resultant series resistance from the diodes and the connected load resistance, V_L is the resistive load voltage. From Figure 5(a) the power dissipated in the resistance of the diodes (and connected load); P_L is given by Equation (9), where R_L is the series resistance of the diodes and load:

$$P_L = \frac{V_L^{\ 2}}{R_L} \tag{9}$$

The source power; P_S is given by Equation (10), where V_S* is the root mean squared (RMS) antenna captured source voltage. Half of the source power is transferred to the resistance of the diodes (and connected load) at match conditions as described by the maximum power transfer theorem:

$$P_S = \frac{V_S^{\ 2}}{R_A} \quad \text{or} \quad P_S = \frac{V_{S*}^{\ 2}}{2R_A} \tag{10}$$

Equating P_L and half RMS P_S gives a condition of maximum voltage gain for the matched RF to DC power converter shown in Figure 5(a):

$$\frac{V_L}{V_{S*}} = \frac{1}{2}\sqrt{\frac{R_L}{R_A}} \tag{11}$$

From Equation (8), substituting the series and parallel resistance ratio into Equation (11) the voltage gain can be expressed in terms of the loaded quality factor as in Equations (12) and (13), where Q is the loaded quality factor of the RF to DC power converter:

$$\frac{V_L}{V_{S*}} = \frac{1}{2}\sqrt{\frac{1}{1 + Q^2}} \tag{12}$$

Equation (12) is the voltage gain in-terms of the loaded Q if the resistance of the diodes (and connected load) is part of the series matching network and the resistance of the antenna source is part of the parallel matching network as in Figure 5(a). If the resistance of the diodes is part of the parallel matching network, then Equation (13) may be written as the voltage gain in-terms of the loaded Q in an L-matched circuit:

$$\frac{V_L}{V_{S*}} = \frac{1}{2}\sqrt{1 + Q^2} \tag{13}$$

Equations (12) and (13) shows that the maximum voltage gain is directly related to the relative differences between the diodes (and connected load) resistance and source resistance at matched conditions or the circuit loaded quality factor. It is interesting to note that the circuit shown in Figure 5(a) has a loaded Q of 2, but an HSMS-286C unloaded quality factor of 50 (at 434 MHz for −30 dBm).

Figure 5(a) is generally modeled as capacitive coupling of two series RLC resonators with a voltage source. This linearized model can be made at any defined frequency and power level. The model however neglects the metal/semiconductor physics of the diode's junction potentials which results in a Schottky barrier. The first series RLC resonator is modeled as impedance from the antenna with or without some passive matching components. The voltage source V_S, is the antenna captured electromagnetic voltage. The second series RLC resonator is the impedance from the diodes (at a defined condition), connected resistance and some passive matching components. Ck is modeled as the coupling element between the two series RLC resonators. Figure 5(b) gives a more general look at the special scenario shown in Figure 5(a). The voltage equations in the two loops are given by Equations (14,15) according to Kirchhoff's voltage loop laws, where ω is the angular frequency and I_1, I_2 are the currents in the first loop and second loop, respectively:

$$V_S = I_1\left[R_A + j\omega L_A - \frac{j}{\omega C_A} - \frac{j}{\omega C_K}\right] + \frac{jI_2}{\omega C_K} \tag{14}$$

$$0 = \frac{jI_1}{\omega C_K} + I_2\left[R_L + j\omega L_L - \frac{j}{\omega C_{DS}} - \frac{j}{\omega C_K}\right] \tag{15}$$

Using Cramers rule, I_2 can be expressed as:

$$I_2 = \frac{\dfrac{-jV_S}{\omega C_K}}{\left[R_A + j\omega L_A - \dfrac{j}{\omega C_A} - \dfrac{j}{\omega C_K}\right]\left[R_L + j\omega L_L - \dfrac{j}{\omega C_{DS}} - \dfrac{j}{\omega C_K}\right] + \dfrac{1}{\omega^2 C_K^2}}. \quad (16)$$

The voltage across R_L is V_L; given by I_2R_L:

$$V_L = \frac{\dfrac{-jV_S}{\omega C_K} R_L}{\left[R_A + j\omega L_A - \dfrac{j}{\omega C_A} - \dfrac{j}{\omega C_K}\right]\left[R_L + j\omega L_L - \dfrac{j}{\omega C_{DS}} - \dfrac{j}{\omega C_K}\right] + \dfrac{1}{\omega^2 C_K^2}} \quad (17)$$

The voltage gain of the coupled resonator can be expressed as in Equation (18):

$$\frac{V_L}{V_S} = \frac{\dfrac{-jR_L}{\omega C_K}}{\left[R_A + j\omega L_A - \dfrac{j}{\omega C_A} - \dfrac{j}{\omega C_K}\right]\left[R_L + j\omega L_L - \dfrac{j}{\omega C_{DS}} - \dfrac{j}{\omega C_K}\right] + \dfrac{1}{\omega^2 C_K^2}} \quad (18)$$

At resonance, there is no resultant reactance in the RLC resonators or the capacitive and inductive impedances become equal; hence Equation (19) can be written:

$$\omega L_A - \frac{1}{\omega}\left\{\frac{1}{C_A} + \frac{1}{C_K}\right\} = 0 \text{ and } \omega L_L - \frac{1}{\omega}\left\{\frac{1}{C_{DS}} + \frac{1}{C_K}\right\} = 0 \quad (19)$$

Equations in Equation (19) can be used to find the resonant frequencies of the series coupled resonator. The voltage gain of the coupled resonator at resonance can then be expressed as in Equation (20):

$$\frac{V_L}{V_S} = V_{gain} = \frac{\dfrac{-jR_L}{\omega C_K}}{R_A R_L + \dfrac{1}{\omega^2 C_K^2}} \quad (20)$$

where V_{gain} is the voltage gain. V_{gain} at resonance is a function of the resistance of the source and load and the coupling element. The maximum of Equation (20) is obtained when:

$$\frac{dV_{gain}}{dC_K} = 0. \quad (21)$$

This gives the results as in Equation (22):

$$\frac{dV_{gain}}{dC_K} = \frac{j2R_L}{\omega^3 C_K^4} - j\left\{R_A R_L + \frac{1}{\omega^2 C_K^2}\right\}\frac{R_L}{\omega C_K^2} = 0 \text{ or } R_A R_L^2 = \frac{R_L}{\omega^2 C_K^2} \quad (22)$$

Equation (22) can be simplified to find $C_{K(max)}$:

$$C_{K(\max)} = \pm\frac{1}{\omega}\sqrt{\frac{1}{R_A R_L}} \quad (23)$$

where C_{Kmax} is the value of the coupling element where maximum power transfer from the first resonator to the second resonator occurs. Using Equations (19) and (23) the unknown optimal matching impedances can be found from the known impedances just like the classical L-matched procedure using Equations (5,6) and (8). By substituting $C_{K(max)}$ into Equation (20) and taking the magnitude of V_{gain}, gives the maximum voltage gain of the coupled series resonator at resonance:

$$\left|\frac{V_L}{V_S}\right| = \frac{1}{2}\sqrt{\frac{R_L}{R_A}} \text{ or simply } \frac{V_L}{V_{S^*}} = \frac{1}{2}\sqrt{\frac{R_L}{R_A}} \tag{24}$$

For wireless harvesters consisting of an antenna and a diode rectifying circuit, the diode resistive impedance at any condition is dependent on the diode realized parameters, signal frequency, connected load and the input power level. The source impedance is determined by the impedance of the antenna. For maximum efficiency, the ratio of the source resistance to the load resistance must tend to zero at matched conditions. The efficiency η of the circuit is given by Equation (25):

$$\eta = \frac{P_L}{P_S}\,;\, \eta \rightarrow 1 \;\; when \;\; \frac{R_A}{R_L} \rightarrow 0 \tag{25}$$

2.5.3. L-Match RF to DC Converter Experimental Results and Discussion

The presented circuit was L-matched between the 50 Ω resistance of the antenna source and the resistance of the HSMS-285C diodes (and load) at 434 MHz for −30 dBm input as shown in Figure 6. Since the series equivalent resistance of the HSMS-285C diodes and load (72 Ω) is greater than the 50 Ω series resistive antenna source, the diode is taken as parallel matching network with a parallel equivalent impedance of $-j510(3519)/(-j510 + 3519)$ Ω. The analysis follows the same procedure as in Section 2.5.2 after this step. Figure 6(b) shows the resultant L-matched RF to DC power converter. C_{DP}* is the resultant shunt matching capacitance.

Figure 6. (**a**) L-matched impedance circuit for matching the HSMS-285C diodes at 434 MHz for −30 dBm input. (**b**) Resultant network, (**c**) PCB layout of the L-matched Delon doubler with adjusted values on FR4 substrate (**d**) Fabricated PCB of the L-network matched Delon voltage doubler.

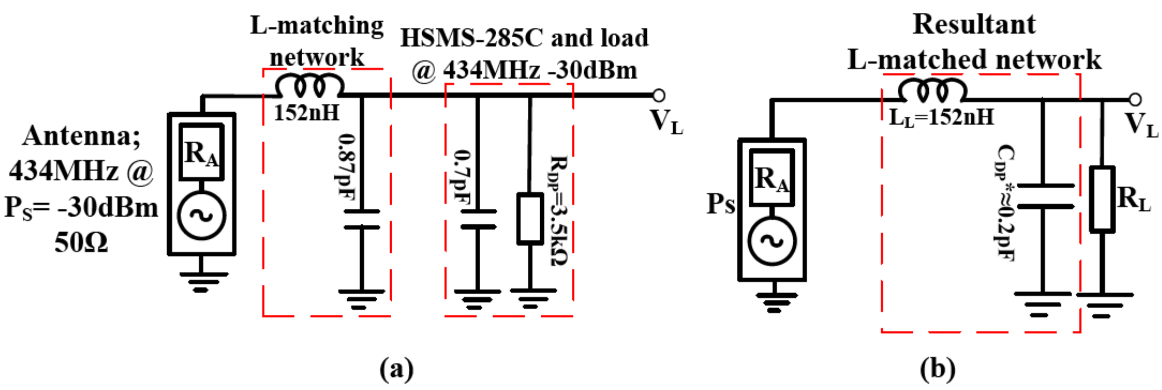
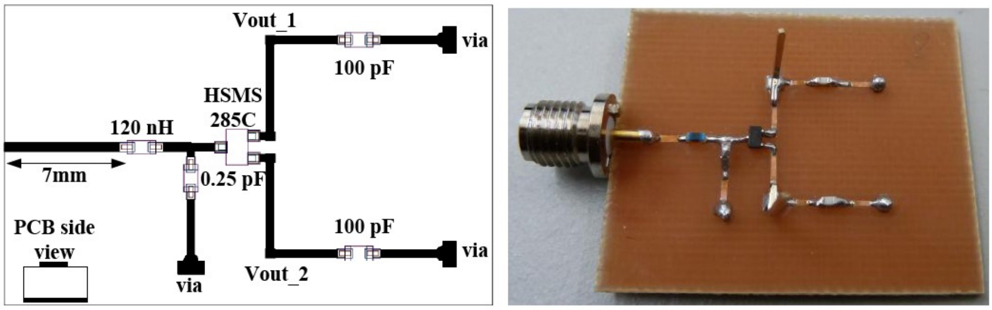


Figure 6. *Cont.*



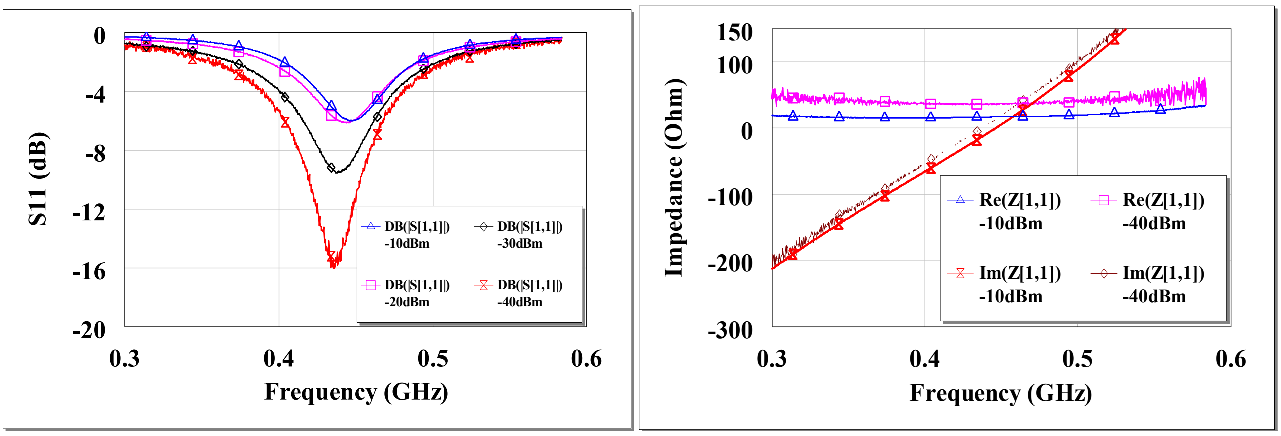
(c) **(d)**

Figure 6(a,b) assume perfect characteristic impedance between the various components in the matched circuit. When a copper route is introduced between components and on a material substrate, it must be accounted for in the total impedance as seen by the source or load. This PCB impedance compensation is carried out in Advance Design Systems (ADS) from Agilent [36]. ADS has extensive models for microstrip substrates to account for its impedances. The optimized layout using ADS microstrip models and its compensated values in the passive tuning components for a Delon doubler is shown in Figure 6(c).

The circuit reflection coefficient (S_{11}) and input impedance at open circuit are shown in Figure 7. There is high return loss and resonance around 434 MHz. The circuit input impedance at open circuit conditions is ~38 Ω at resonance for −40 dBm and ~17 Ω at −10 dBm input.

The measured L-matched circuit efficiency and voltage sensitivity is shown in Figure 8. The maximum measured L-matched efficiency at −30 dBm is 22% at ~20 kΩ load and an open circuit voltage of 124 mV. At −10 dBm, the maximum efficiency and open circuit voltage is 47% and 2 V respectively. At the optimal load of ~20 kΩ, the detected voltage is 58 mV and 1 V at −30 dBm and −10 dBm respectively.

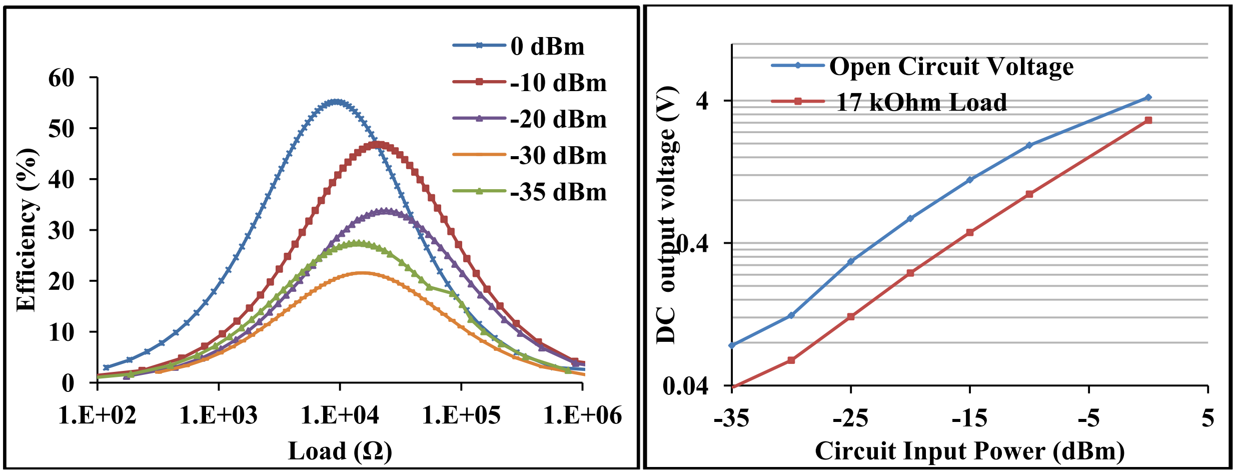
Figure 7. Measured open circuit S_{11} of the L-matched Delon circuit at different input power levels from a 50 Ω source (**left**), measured open circuit input impedance at −10 dBm and −40 dBm of the L-matched circuit (**right**).



The open circuit voltage gain is 25 at −30 dBm and 40 at −10 dBm. The maximum measured efficiency at −35 dBm is 27%. This is higher than that of −30 dBm due to the better matched circuit

impedance at −35 dBm (35 Ω) than at −30 dBm (27 Ω) input. The L-matched RF to DC power converter has a loaded *Q*, sensitivity and efficiency determined mainly by the diodes resistance, diodes junction potential, connected resistance and antenna source resistance at matched conditions.

Figure 8. Measured L-matched circuit efficiency *versus* resistive load at various input power levels at 434 MHz (**left**), measured open circuit voltage and at 17 kΩ load *versus* input power at 434 MHz (**right**).



2.5.4. PI-match RF to DC Power Converter

A highly selective or small frequency bandwidth RF power converter is realized with a PI-network in-between the source impedance from the antenna and the diode rectifier. A PI-network is a 'back to back' L-network that are both configured to match the load and source impedance to an invisible resistance located at the junction between the two L-networks [37]. The quality factor of the L-network with the parallel resistance is given by Equation (26):

$$Q_P^* = \sqrt{\frac{R_P}{R^*} - 1}, \tag{26}$$

where R_P is the parallel resistance, R^* is a virtual resistance and $Q_P{}^*$ is the quality factor of the L-network with the parallel resistance. The quality factor of the L-network with the series resistance is given by Equation (27):

$$Q_S^* = \sqrt{\frac{R_S}{R^*} - 1}, \tag{27}$$

where $Q_S{}^*$ is the quality factor of the L-network with the series resistance. The unloaded quality factor; $Q_S{}^*$ or $Q_P{}^*$ is set higher than what is normally achieved with a single L-network [37] to realize the small frequency bandwidth circuit. The resistance of the load is assigned the parallel network in a PI-matched circuit if its series equivalent resistance is higher than the source series equivalent resistance; the opposite is true if the source is higher than the load. Equation (26) and Equation (27) are synonymous to Equation (8), except the lowest resistive impedance in Equation (8) is substituted with the virtual resistance which is dependent on the newly desired circuit selectivity. From Equations (26) and (27) the loaded quality factor of the PI-matched circuit can be written as Equation (34) in terms of $Q_S{}^*$ and $Q_P{}^*$:

$$Q^2 = \left[\left(\frac{Q_P^{*2} + 1}{Q_S^{*2} + 1} \right) - 1 \right], \tag{28}$$

where Q is the loaded quality factor of the PI-network. Q_S* or Q_P* are the unloaded quality factors of the PI-matched network. The larger value among the unloaded quality factors result in small frequency bandwidth response which is desired when matching a source and load impedance with a PI-network. Some authors approximate the highest value of Q_S* or Q_P* or their algebraic sum as the loaded quality factor of the PI-network as in [35] and [37], but Equation (28) gives the exact loaded Q of the PI-matched circuit in terms Q_S* and Q_P*. This allows for the correct estimation of the maximum voltage gain from the loaded quality factor.

2.5.5. Selectivity RF to DC Converter Generalized Analytical Model

An example of a PI-matched RF to DC converter using the HSMS-285C diodes operating at 434 MHz for −30 dBm input is presented first and then the generalized model is discussed. The circuit is matched for Q_P* of 60 between the antenna and the resistance of the diodes as shown in Figure 9.

Figure 9. Impedance diagram of PI-matched RF power converter; (**a**) Impedance diagram of 50 Ω source and the HSMS-285C diodes at 434 MHz, (**b**) Resultant PI matched network between the antenna source and load resistance.

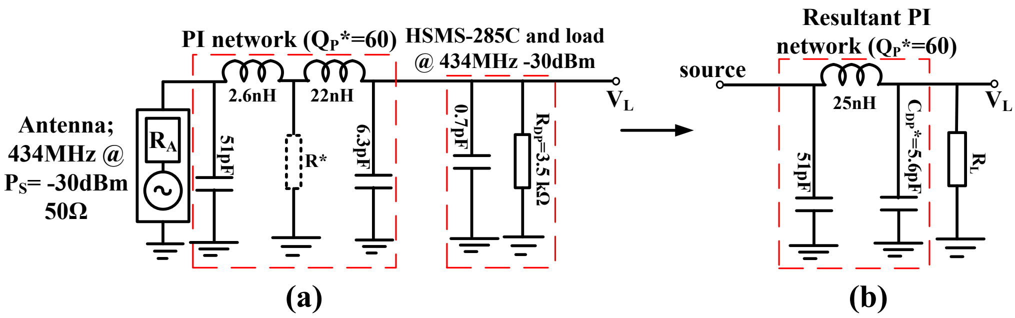
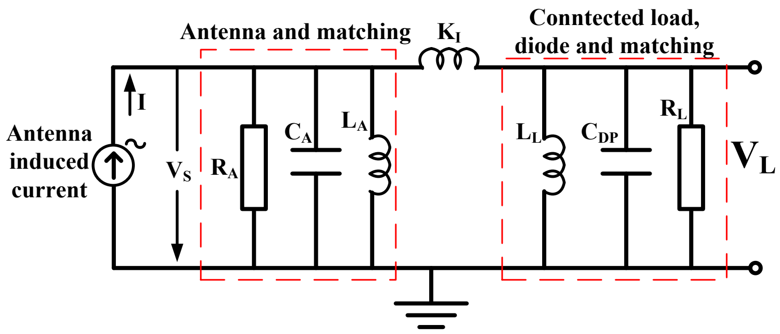


Figure 9(b) can also be modeled as an inductive coupling of two parallel RC circuits. A more general look at such a circuit is shown in Figure 10, as an inductive coupling of two parallel RLC resonators with a current source.

Figure 10. Inductive coupled parallel RLC small signal model of a generalized PI-matched antenna and diode rectifier.



The first parallel RLC resonator is modeled as impedance from the antenna and some passive matching components. The second parallel RLC resonator is modeled as impedance from the linearized diodes, its connected load and some passive matching components. I is the antenna induced current, V_S this time is the voltage across the parallel R_A and K_1 is the coupling element between the two parallel resonators. Using Kirchoff's current laws, the node equations can be expressed as Equations (29) and (30):

$$I = V_S\left[\frac{1}{R_A} + j\omega C_A - \frac{j}{\omega L_A} - \frac{j}{\omega K_1}\right] + \frac{jV_L}{\omega K_1} \tag{29}$$

$$0 = \frac{jV_S}{\omega K_1} + V_L\left[\frac{1}{R_L} + j\omega C_{DP} - \frac{j}{\omega L_L} - \frac{j}{\omega K_1}\right] \tag{30}$$

Load voltage (V_L) and the source voltage (V_S) at resonance are given by the equations in Equation (31). The resonance frequencies are given by Equation (32):

$$V_L = \frac{\frac{-jI}{\omega K_1}}{\left[\frac{1}{R_A R_L} + \frac{1}{\omega^2 K_1^2}\right]} \quad \text{and} \quad V_S = \frac{\frac{I}{R_L}}{\left[\frac{1}{R_A R_L} + \frac{1}{\omega^2 K_1^2}\right]} \tag{31}$$

$$\omega C_A - \frac{1}{\omega}\left\{\frac{1}{L_A} + \frac{1}{K_1}\right\} = 0 \text{ and } \omega C_{DP} - \frac{1}{\omega}\left\{\frac{1}{L_L} + \frac{1}{K_1}\right\} = 0 \tag{32}$$

From V_L and Vs in Equation (31), the voltage gain at resonance can be expressed as:

$$\frac{V_L}{V_S} = \frac{R_L}{j\omega K_1} \tag{33}$$

The maximum of Equation (33) is obtained when:

$$j\omega K_1 \to 0 \;\; or \;\; R_L \to \infty \tag{34}$$

Since $j\omega K_1$ is restricted by the conditions in Equation (32) to attain resonance, one cannot manipulate $j\omega K_1$ alone without changing the resonance conditions. What can drive the voltage gain is if R_L is very large at resonance conditions. If the input impedance (V_S/I) of the coupled resonator is maximum at resonance, conditions in Equation (35) hold:

$$\left(\frac{Vs}{I}\right) \to maximum \;\; when \;\; \frac{R_L}{\omega^2 K_1^2} \to 0 \tag{35}$$

Equation (36) may be assumed when $\frac{R_L}{\omega^2 K_1^2} \to 0$:

$$\frac{V_S}{I} = R_A \tag{36}$$

Under these conditions and an optimal coupling coefficient K_{1max}, the maximum voltage gain of the parallel coupled resonator can be written as in Equation (37), where K_{1max} is given by Equation (38):

$$\left|\frac{V_L}{V_S}\right| = \left|V_{gain}\right| = \left|\frac{1}{2}\sqrt{\frac{R_L}{R_A}}\right| \tag{37}$$

$$K_{1(\max)} = \mp\frac{1}{\omega}\sqrt{R_A R_L} \tag{38}$$

The analysis of Section 2.5.2 and parallel coupled RLC resonators show that any antenna and matched rectifying diode can be described as an equivalent circuit of a coupled resonator at a defined operating point. This general model can be applied to optimize other harvesters with complex output impedance such as piezo-harvesters or vibration harvesters for maximum transfer of power or voltage to its connected load. The model can also be applied to near field magnetically coupled antennas/coils for optimization.

2.5.6. Broadband RF to DC power converter

A broadband network is preferred when an RF to DC power converter is to be operated for a wide range of frequencies. A broadband converter is realized by connecting successive L-networks together in a multi-network between the antenna source and the rectifying diodes. The result is broadband or multiband RF power converter around certain frequencies. This can be deduced from the general model of a coupled resonators that by choosing certain passive components between a source and the load, it is possible to have more frequencies (ω) fulfilling Equation (32) and hence a result of multiple resonant frequencies or broader bandwidth at match conditions. For a two stage L-connected match, the quality factor of the L-network with the parallel resistance is given by Equation (39):

$$Q_P^{\ast} = \sqrt{\frac{R_P}{R^{\ast}} - 1} \tag{39}$$

The quality factor of the L-network with the series resistance is given by Equation (40):

$$Q_S^{\ast} = \sqrt{\frac{R_{\ast}}{R_S} - 1} \tag{40}$$

From Equations (39) and (40) the loaded quality factor of the two stage L-connected broadband network may be written as Equation (41) in terms of the unloaded quality factors; Q_S* and Q_P*:

$$Q^2 = \{(Q_P^{\ast 2} + 1)(Q_S^{\ast 2} + 1)\} - 1 \tag{41}$$

$R^{\ast}$ in this case may be chosen if it is larger than R_S and lower than the R_P. The highest possible bandwidth between a resistive source and resistive load is found for a virtual resistance ($R^{\ast}$) given in Equation (42) [37]:

$$R^{\ast} = \sqrt{R_S R_P} \tag{42}$$

For complex loads such as rectifying diodes or transistors, the largest achievable bandwidth prescribed by Equation (42) is limited by the load or source component quality factor, since Equation (42) does not take into account reactive impedance associated with the source or load.

2.5.7. Broadband-Match RF to DC Converter Results and Discussion

The antenna source resistance was broadband matched to the HSMS-285C diodes (and load) resistance at −30 dBm input around 434 MHz. For a desired Q_P* and Q_S* of 2.7 there is ~0.4 pF inherent diode capacitance which is un-tuned using a two stage L-matching network [Figure 11(b)]. This is because the HSMS-285C diodes provides an inherent component quality factor of 6.96 at 434 MHz for −30 dBm input, hence a broadband circuit with Q_P* lower than this inherent component quality factor of the diodes (and load) is difficult to achieve without trade-offs. However, connected L-networks with Q_P* as high as the diode component quality factor may perform worse than a single L-matched network with similar loaded quality factor. This is due to redundant components of the connected L-networks which have inherent losses.

Figure 11. Impedance diagram of broadband RF power converter; (**a**) Broadband match around 434 MHz with loaded Q of 2.7, (**b**) Resultant impedance matching network with un-turned capacitance of 0.4 pF.

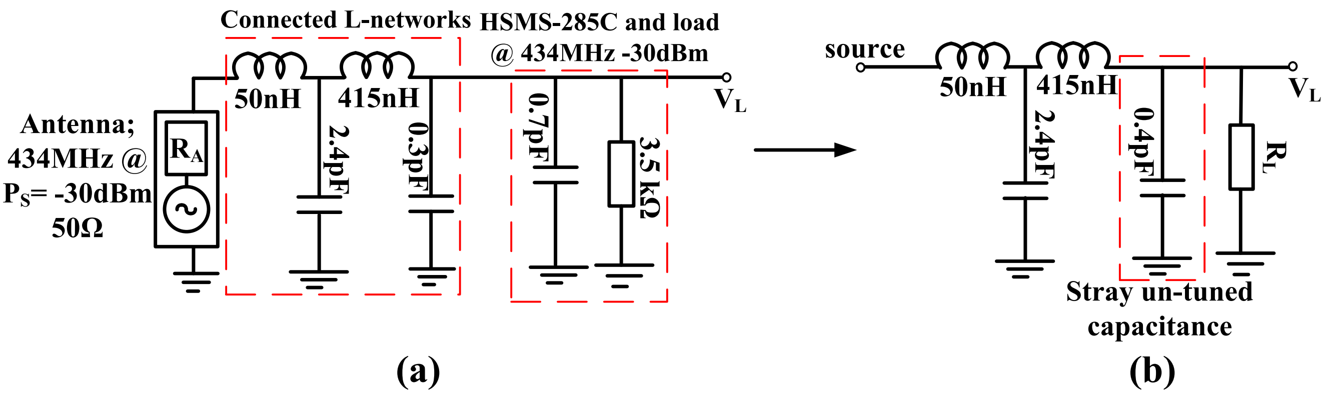
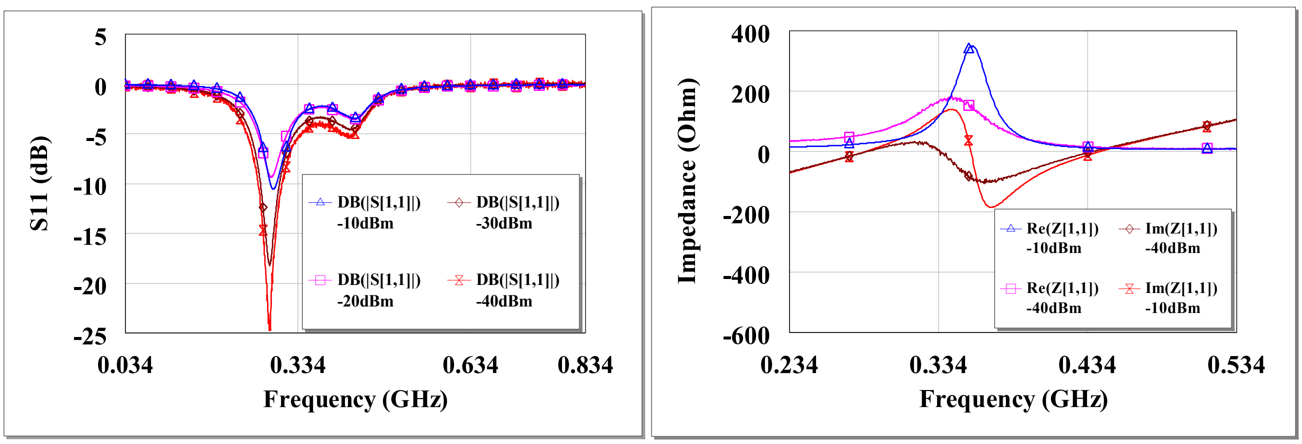


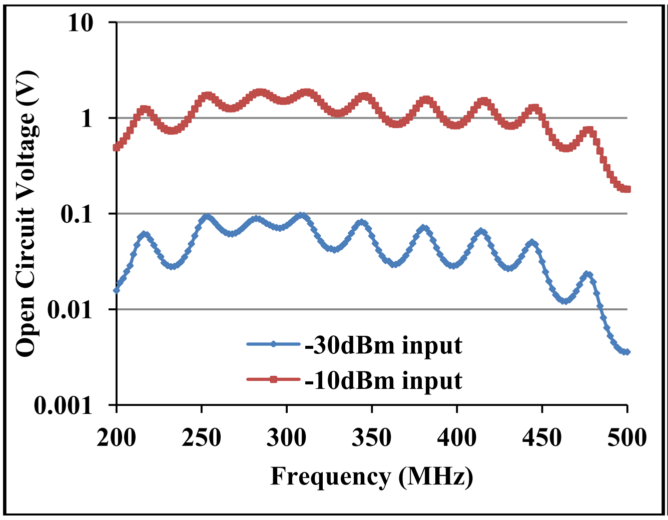
Figure 12. Measured open circuit S_{11} of the broadband circuit around 434 MHz at different input power levels from a 50 Ω source (**left**), measured open circuit input impedance at −10 dBm and −40 dBm of the broadband circuit (**right**).

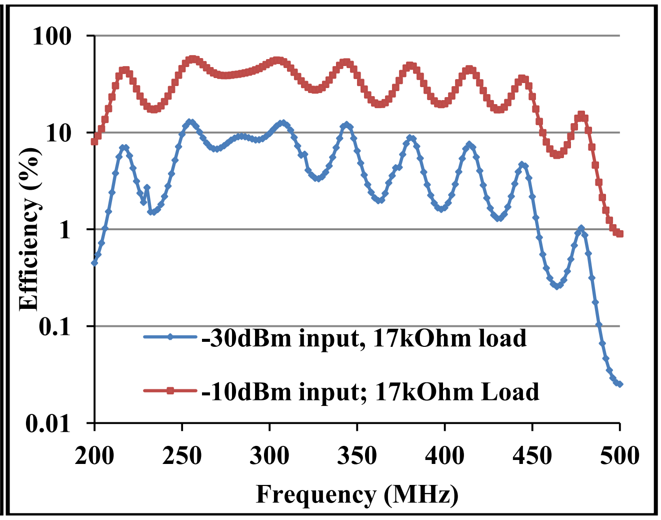


Therefore the broadband circuit is matched for Q_P* of 2.7, notwithstanding the un-tuned shunt capacitance as can be seen in Figure 11(b). Figure 12 shows the circuit S_{11} at various input power levels and input impedance at open circuit conditions. From Figure 12 (left) there is ~−5 dB return loss

from 200 MHz to 500 MHz providing an operating band of ~300 MHz. The impedance of the circuit shows resonances at ~290 MHz and ~450 MHz as shown in Figure 12(right). A third resonance occurs around 356 MHz at −10 dBm as the frequency of highest harvester input resistance (~350 Ω) and where the reactive impedances approach their extremes. Figure 12 show that a wireless EM harvester can exhibit different resonance scenarios depending on the dominant instantaneous conditions. The efficiency and voltage sensitivity of the broadband matched wireless EM harvester are shown in Figure 13. The average open circuit voltage is 47 mV and 1.1 V at −30 dBm and −10 dBm, respectively, when operating from 200 MHz to 500 MHz.

Figure 13. Measured open circuit voltage *versus* frequency sweep from 200 MHz to 500 MHz for −10 dBm and −30 dBm (**left**), measured efficiency at 17 kΩ load *versus* frequency sweep for −10 dBm and −30 dBm (**right**).





The broadband circuit achieves average efficiency of 5% at 17 kΩ load for −30 dBm and 30% at 17 kΩ load for −10 dBm input power from 200 MHz to 500 MHz. Figure 13 further confirm a direct link between frequency response and the unloaded quality factors. For Q_S* and Q_P* of ~2.7, the circuit response is broadband around 434 MHz.

2.6. High Voltage Sensitive RF to DC Converter

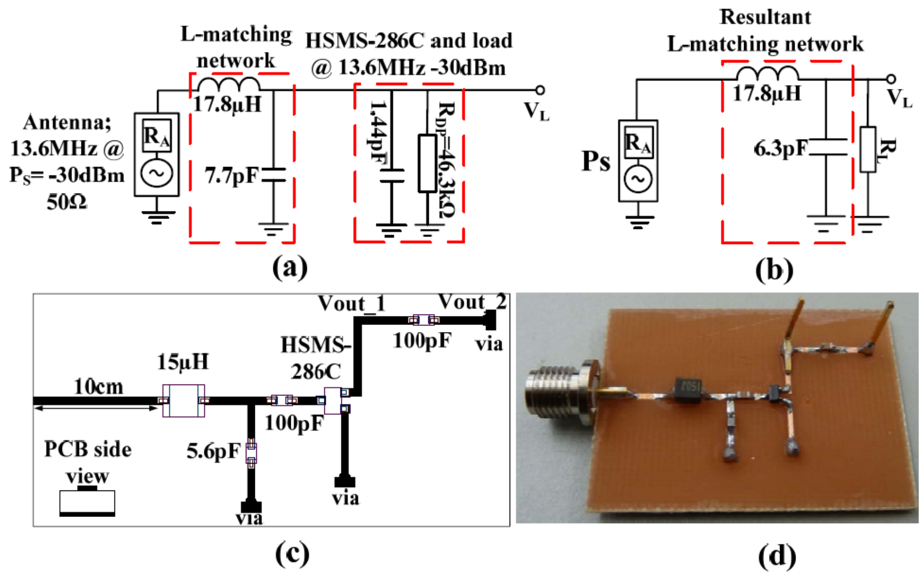
The current state of the art low power remote sensors would require a DC voltage supply of about 1 V and DC current of about 30 μA for operation. Therefore, the issue is not only how efficient a wireless EM harvester is in converting RF to DC power, but also what the output DC voltage and current of the EM harvester are at the RF input power level [38]. Equations (11,24) and (33) show that the maximum voltage sensitivity of a coupled resonator system or an RF to DC power converter is mostly related to the load and the source resistances at resonance. Therefore high voltage sensitive wireless EM harvester can be achieved with a diode voltage doubler with a very high input resistance relative to the antenna source without the need to cascade the diodes as in voltage multipliers. If the diodes been used for the RF to DC power conversion cannot provide high resistive impedance at the working frequency relative to the antenna source, then a DC-DC converter can be applied after the EM harvester as presented in [39] or the diodes may be cascaded by way of multipliers as presented in our

earlier work [40] and by several other authors [3,5,14]. In case of multipliers, the input voltage ought to be high enough to overcome the junction potential of the several diodes in the multiplier network. If frequency is not a constraint, then a frequency sweep *versus* impedance for the diodes can be made and the frequency where the diodes exhibits high resistive impedance can be used to realize high voltage sensitive wireless RF harvester. For Schottky diodes, high resistive impedance occurs mostly at lower frequencies (see Figure 3). The measured voltage gain of a high resistive diode pair (voltage doubler) is presented in the next results.

2.6.1. High Voltage Sensitive RF to DC Converter Results and Discussion

The presented result was L-matched using 50 Ω resistance of the antenna source and the resistance of the HSMS-286C diodes (and load). The HSMS-286C diodes do provide high resistive impedance at low frequencies; notwithstanding the flicker noise which causes its resistive (and reactive) impedance to fluctuate. The HSMS-286C has low forward junction potential (~350 mV at 1 mA) per diode and series impedance of ~1.5–j8.1 kΩ or parallel impedance of ~−j8.3(46.3)/(−j8.3 + 46.3) kΩ at 13.6 MHz for −30 dBm input. Even though the HSMS-286C diodes unloaded component quality factor at 13.6 MHz is similar to that of the HSMS-285C diodes at 434 MHz, the elevated resistive impedance at 13.6 MHz fulfills the condition for high voltage sensitivity relative to a 50 Ω antenna source at resonance conditions.

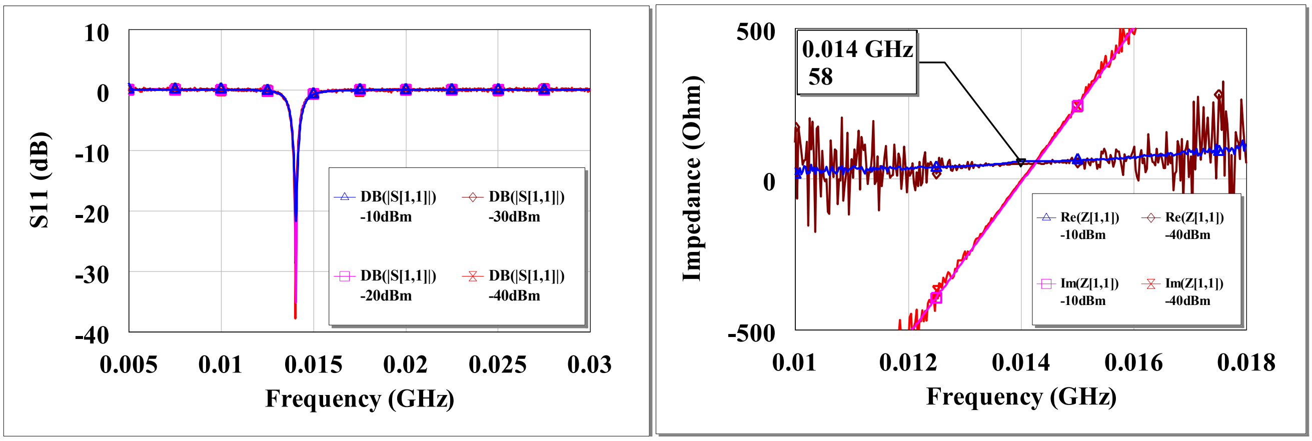
Figure 14. (**a**) L-matched impedance diagram for matching the HSMS-286C diodes at 13.6 MHz at -30 dBm input. (**b**) Resultant network, (**c**) PCB layout of the L-matched Greinacher doubler with adjusted values due to impedances provided by copper route on FR4 substrate with thickness of 1 mm. (**d**) Fabricated PCB of the L-matched RF to DC power converter.



The high voltage sensitive EM harvester operating at 13.6 MHz is as shown in Figure 14. On the realized PCB is a Greinacher doubler. An inductance of 15 µH and a shunt capacitance of 5.6 pF were the adjusted values after the microstrip contributions.

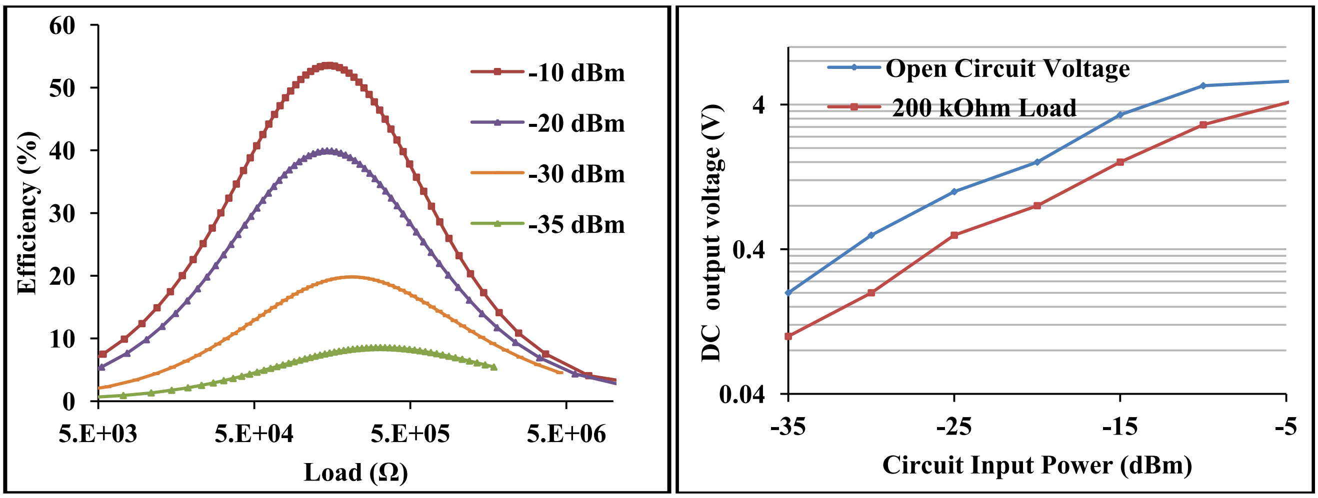
The measured S_{11} and input impedance at open circuit are shown in Figure 15. There is high return loss and resonance around 13.6 MHz. The circuit input impedance at open circuit conditions is 58 Ω at resonance for both −40 dBm and −10 dBm.

Figure 15. Measured open circuit S_{11} of the L-matched HSMS-286C diodes at 13.6 MHz for different input power levels from a 50 Ω source (**left**), measured open circuit input impedance at −10 dBm and −40 dBm of the L-matched HSMS-286C diode at 13.6 MHz (**right**).



The efficiency and voltage sensitivity of the high voltage sensitive wireless EM harvester are shown in Figure 16.

Figure 16. Measured circuit efficiency *versus* load at various input power levels at 13.6 MHz (**left**), measured open circuit voltage and at 200 kΩ load *versus* input power at 13.6 MHz (**right**).



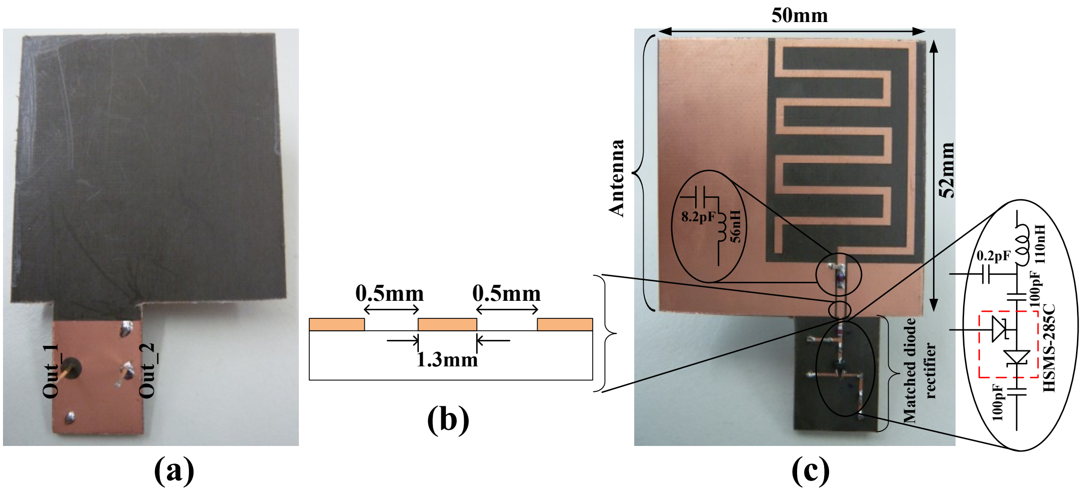
The maximum measured efficiency at −30 dBm is 20% for ~200 kΩ load and an open circuit voltage of 0.5 V. At −10 dBm, the maximum efficiency and open circuit voltage are 54% and 5.4 V respectively. At the optimal load of ~200 kΩ, the detected voltage is 0.2 V and 2.9 V at −30 dBm and −10 dBm respectively. The open circuit voltage gain is 100 at −30 dBm and 108 at −10 dBm.

Even though the RF to DC converter presented in Section 2.5.3 is the same as the L-match circuit realized with the HMSM-286C diodes at 13.6 MHz, the voltage gain is increased by a factor of 4 due to the large difference between the diodes (and load) resistance and source resistance so that at matched conditions high voltage gain occurs. The loaded Q of the L-matched circuit is 30 which results in small frequency bandwidth just like a PI-matched diode rectifier presented in our earlier work [40]. From this result and the results from our earlier presented PI-matched EM harvester, it can be inferred that all high loaded Q RF to DC circuits have high selectivity but not all highly selective RF to DC circuits have high loaded Q. The voltage sensitivity of the matched HSMS-286C diode at 13.6 MHz can be improved if its resistive impedance is not lowered by the flicker noise.

3. Wireless EM Power Harvester

A wireless EM harvester, consisting of a rectifying antenna (*rectenna*) was designed to find a compromise between size and performance of its antenna. The rectenna is shown in Figure 17.

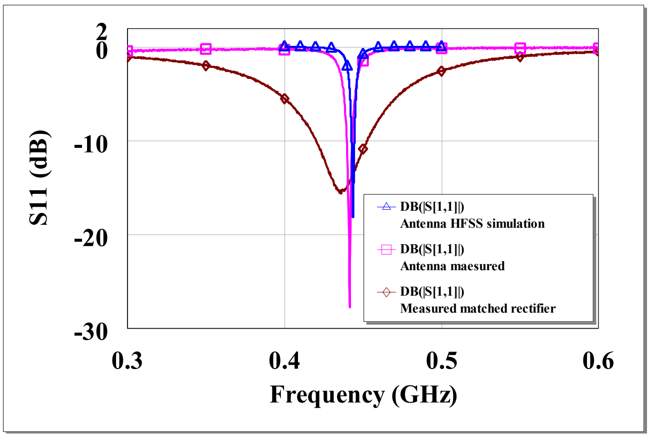
Figure 17. Rectenna realized on a Duroid 5880, 1.57 mm substrate. (**a**) Backside of the rectenna, (**b**) cross-section of antenna output coplanar stripline dimensions (**c**) frontside of the rectenna.

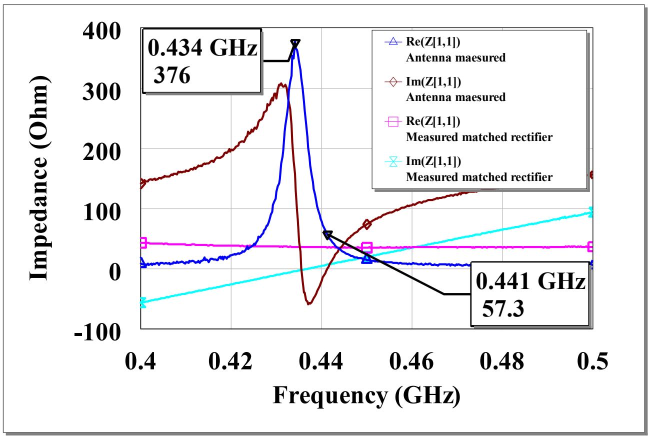


The antenna (planar) part of the rectenna is based on our earlier work [41]. In contrast to the earlier presented antenna, this rectenna is realized on a Duroid [42] substrate of thickness 1.57 mm. Duroid 5880 has lower loss tangent of 0.0004 at 1 MHz compared to 0.025 at 1 MHz for FR4. This means there is less loss in the transmission of signals on a Duroid PCB at this frequency range. The antenna part is fabricated to resonate around 434 MHz; hence its dimensions of 5 × 5.2 cm make it electrically small. The antenna is tuned with a chip inductor and a capacitor to achieve the resonance frequency around 434 MHz [Figure 17(c)]. This is done at a cost of reduced antenna radiation efficiency. An antenna is one of the few components the size of which is related to the operating frequency. Thus, if the size of an antenna is fixed, resonance frequency reduction of the antenna can only be achieved with penalty factors [10]. The antenna's output impedance is tuned with the dimensions of the coplanar stripline as shown in Figure 17(b).

HFSS [43] was used to simulate the presented antenna and to find the correct capacitive and inductive components for frequency tuning before the optimized design was fabricated. The simulated antenna resonances occur at 438 MHz and 445 MHz. At these frequencies, the radiation efficiency is 20% and a peak gain of −6 dBi. The rectifying part of the rectenna consists of L-matched HSMS-285C diodes (Figure 17(c)). The L-matched HSMS-285C part of the rectenna can be engineered to be as small as possible if required. The separate parts of the rectenna were characterized by terminating their ends and measuring the individual reflection coefficients just like the power converters presented in Section 2. Figure 18 shows the measured antenna and matched rectifier individual S_{11} and impedance. Figure 18 (left) also show the HFSS simulated S_{11} results. From Figure 18 (right), the measured antenna resonance where the input impedance is at maximum is ~434 MHz. At ~434 MHz, the antenna input resistance is 376 Ω and the reactive impedances approach their extreme (*so called anti-resonance*). The other resonance occurs when the input resistance is 'finite' and the reactive impedance is zero; at ~441 MHz. The input resistance is 57 Ω at ~441 MHz. The rectifier circuit is matched for the antenna's resistance at ~441 MHz.

Figure 18. Antenna HFSS simulated, antenna measured, and measured L-matched diode rectifier S_{11} on a Duroid 5880 PCB for −30 dBm input (**left**), Measured open circuit input impedance of antenna and rectifier at −30 dBm input (**right**).





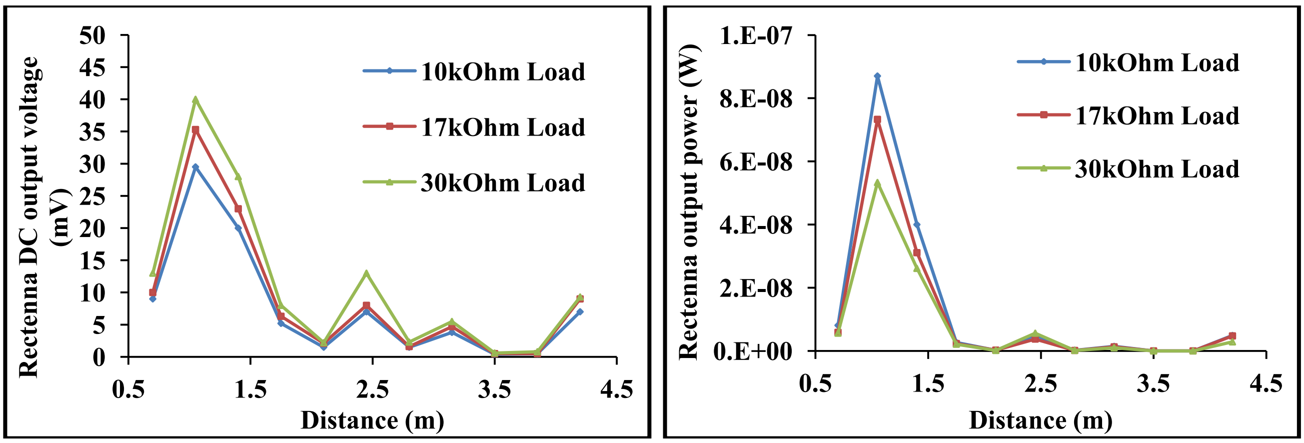
3.1. EM Range Results and Discussion

At far field between wireless EM transmitting and receiving antenna, the coupling mechanism between the transmitting and receiving antenna is neither capacitive nor inductive as is the case for the RF to DC converters. The coupling is radiative which can be described by the Friis equation of transmission on the assumption that the transmitting and receiving antenna are in free space [44]. A modified Friis equation for a transmitting and receiving antenna at far-field (R >> λ and R >> transmitting antenna largest dimension) to each other at a specified direction is given by Equation (43) [45]. Equation (43) assumes real world open space conditions:

$$\frac{P_r}{P_t} = F_{envt} G_t G_r \left(\frac{\lambda}{4\pi R} \right)^2, \tag{43}$$

where *Pr* is the power at the receiving antenna port, *Pt* is the power supplied at the transmitting antenna port, F_{envt} is a factor accounting for environmental effects as such ground reflections among others, *Gt and Gr* are the transmitting and receiving antenna gain (*at specified direction*) respectively. *R* is the distance between the transmitting and receiving antenna and λ is the wavelength of the transmitting EM wave. The rectenna receiving range measurements were carried out in an open space (*hall*) with the antennas 2 m above ground level. The transmitting and receiving antennas were arranged in the direction of their peak gain. The rectenna range performance is shown in Figure 19. According to Equation (43), the efficiency of RF power transferred between a sending and receiving antenna depends on controllable factors like the gain of the antennas in the arranged direction and the radiation efficiency of the antennas. Since the receiving/transmitting antenna's incorporated in remote harvesters for sensor powering are normally small in relation to their operating frequencies, they tend to be less efficient.

Figure 19. Rectenna receiving range performance by sending 17 dBm (50 mW) at a gain of −6 dBi at 437 MHz. Output DC voltage *versus* receiving distance for different loads (**left**), loads output power *versus* receiving distance (**right**).



The efficiency of the rectenna's antenna is ~20% at resonance. A 'perfectly' matched RF to DC power converter operating in its square law region has efficiencies in the region of 20% as depicted in Section 2. The transmitting antenna was the same as the antenna incorporated in the rectenna. By transmitting the EM power with a small antenna (5 cm × 5.2 cm) at 437 MHz with efficiency of ~20% and at a gain of −6 dBi, the power delivered by the rectenna is generally low at far-field from the transmitter as can be seen in Figure 19. A mediocre transmitting antenna was used to transmit the EM waves due to limitations in the European Union about transmitting EM power at certain frequencies; so the goal in the rectenna range experiment is to show the lowest limit functionality of such a harvester. At 4.2 m from the electrically small transmitting antenna transmitting at 17 dBm, the rectenna harvested DC voltage and power are 9 mV and 5 nW respectively for 10 kΩ load. It can be seen from Figure 19 that the harvested voltage/power generally degrades as an inverse square of distance from transmitter as described by Friis equation. The measured received power however alternate along this R^{-2} fit as shown in Figure 19. This anomaly is accounted for by F_{envt} [Equation (43)] as influence of ground reflections and polarization in real world open field measurements [45]. For any particular distance *R*, the signals reflected from ground can be constructive with the direct signal to the rectenna,

in which case the measured power may be higher than that predicted by the original Friss equation as in [44]. The ground effect can also be destructive, in which case the measured power will be lower than what is predicted by the original Friis equation.

4. Conclusions

Optimization of Schottky diode-based RF to DC power converters using different matching techniques for wireless EM energy harvesting applications is presented. Using scattering parameters for small signal modeling, it is shown that wireless EM harvesters can be generally described as coupled resonators with efficiencies and maximum voltage sensitivity depending mostly on the source and load resistances under matched conditions. The analytical models allow systematic control in the design of passive wireless EM harvesters. Based on these analyses, a rectenna is built and tested for lower limit functionality from harvesting ambient EM waves. The analysis presented in this work may also be applied to optimize derivatives of wireless EM harvesters like RFID tags, NFC, wireless chargers *etc.*, for efficient powering of their sensors or integrated circuits. Generally, most energy harvesters and their matched loads can be described as coupled resonators and thus may be optimized with the methods presented in this work.

Acknowledgments

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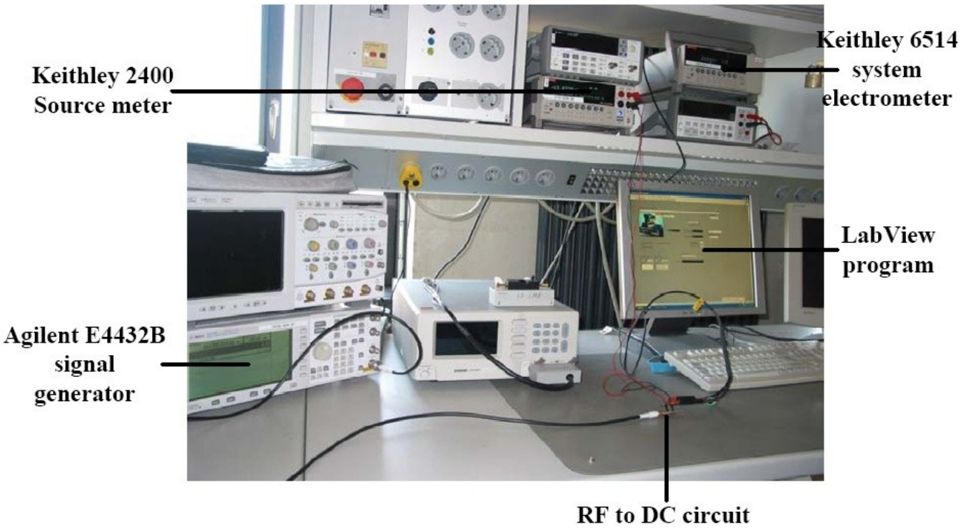
Appendix A: Measuring Setup for RF Rectifier Efficiency and Voltage Sensitivity

The measuring setup is as shown in Figure A1.

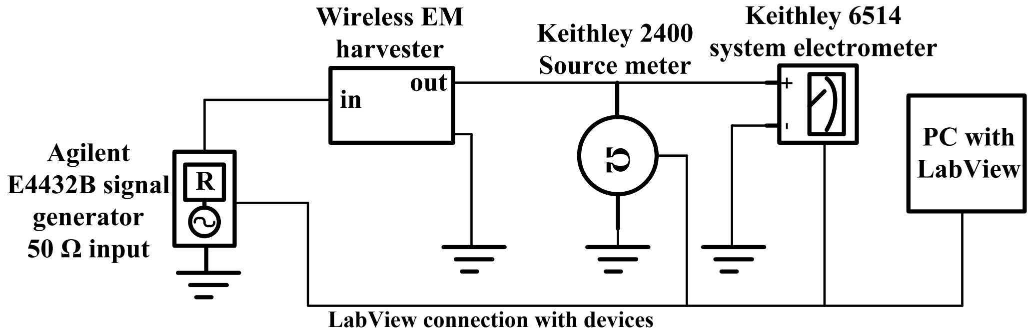
Figure A1. RF to DC Power converter characterization setup.



The RF to DC circuit efficiency and voltage sensitivity measurements were made with a Keithley 2400 source meter and Keithley 6514 system electrometer with an Agilent E4432B signal generator providing 50 Ω RF signal into the circuit board.

The closed circuit current drawn by the RF to DC power converter (*without load*) from the generator is first determined by the Keithley 2400 source meter; then starting from this current, the value of the current is decreased at set intervals to creates virtual load resistances to the circuit for up to a lowest current of 0.1 µA. The 6514 system electrometer is used to measure the output voltage. The number of data point is set through LabView [46] as well as the measurements. Additionally open circuit voltage or at specific loads and frequency sweep can be made through the LabView program. At −40 dBm input power and below, the detected voltages and currents were difficult to measure accurately with the measuring setup; hence measurements were made up to a minimum of -35 dBm input power. The circuit layout for the efficiency and voltage sensitivity measurements is schematically shown in Figure A2.

Figure A2. RF to DC power converter characterization circuit.



Antennas Wireless Technology Comparisons Electronics

What is the difference between slot antenna and patch antenna?

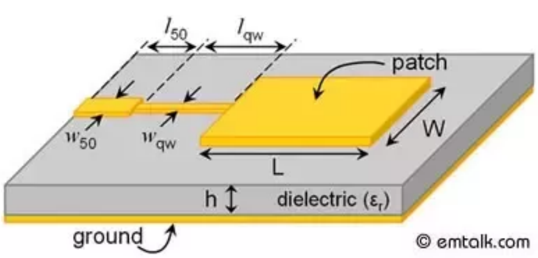
4 Answers

Steven J Greenfield, AE7HD, a lifetime of electronics. Willing to look things up and admit I'm wrong.
Answered Jan 25, 2016

A patch antenna is literally a patch of metal or other conductor on a flat surface. There may or may not be a ground plane on the other side of the substrate. The directionality, gain, polarization, and impedance are a function of the size and shape, and placement of the feed line. Most GPSs use a patch antenna.

Thanks to Dii dot Unimore dot IT for the image:

Thanks to RayMaps dot Com:



They don't have to be rectangular, they can even be circularly polarized. Thanks to CST dot Com for the image and website describing the design and testing of this circularly polarized patch antenna:

Circularly-Polarized Patch Antennas

What are the applications of the U-slot microstrip patch antenna?

What should be the shape of a patch antenna (rectangular or circular) in an UWB (ultra wide band) antenna?

Why are slotted antennas used instead of patch antennas?

How does one fabricate a microstrip patch antenna?

What is the difference between a patch antenna and monopole antenna?

Why microstrip patch antennas have low bandwidth?

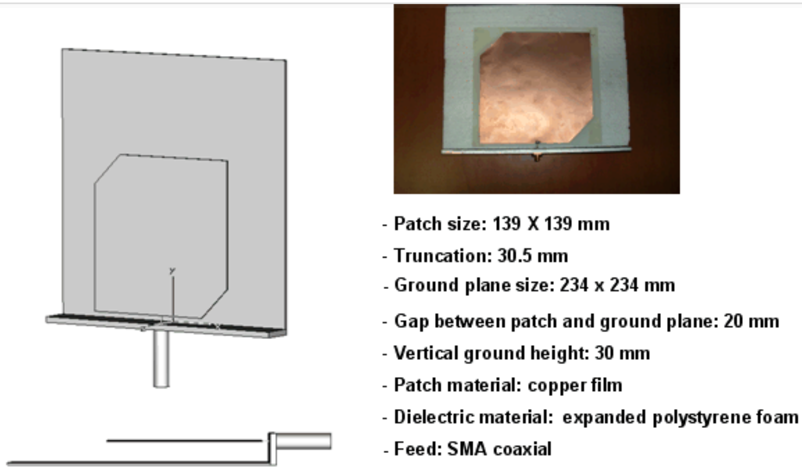
Can a dish antenna be replaced by a microstrip patch antenna? How?

What is an antenna array?

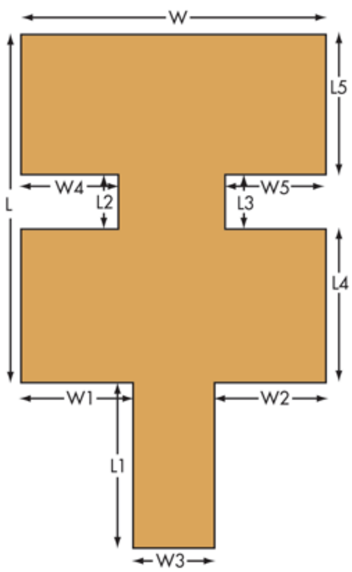
What happens when a slot is inserted in the patch of an antenna?

What is a microstrip patch antenna? What are its applications?

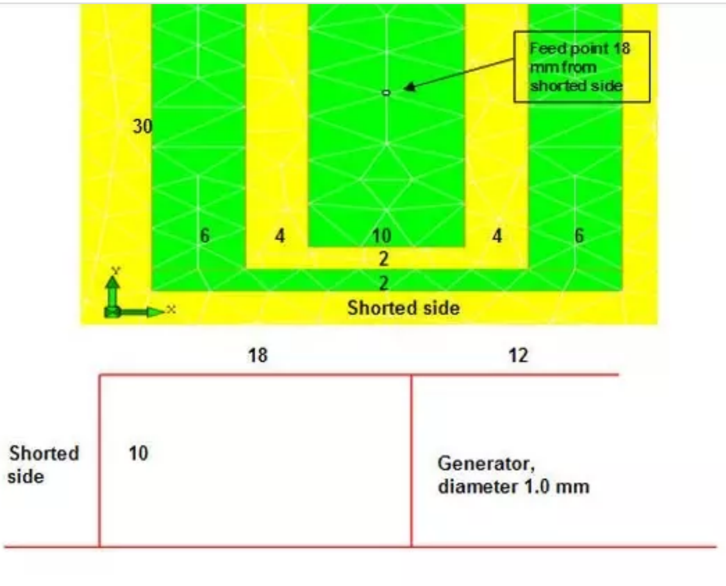
Ask New Question



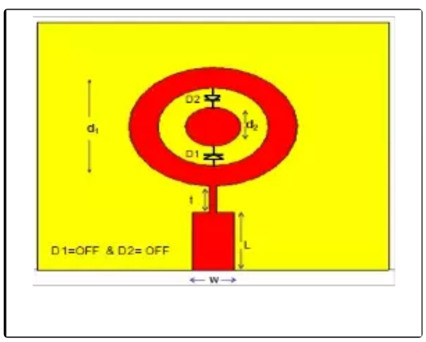
Thanks to MWRF dot Com:



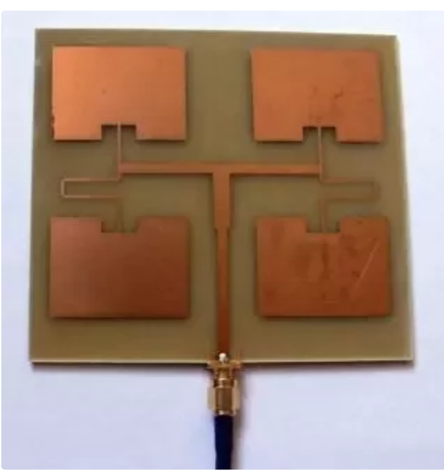
Thanks to EfieldSolutions dot Com, the green is copper:



Thanks to IJSER dot Com for this round patch antenna that is reconfigurable with switching diodes:



Thanks to JCPerez dot Web44 dot Net for this image of a patch antenna array:



GPS patch antenna, thanks to RoundSolutions dot Com:

What are the applications of the U-slot microstrip patch antenna?

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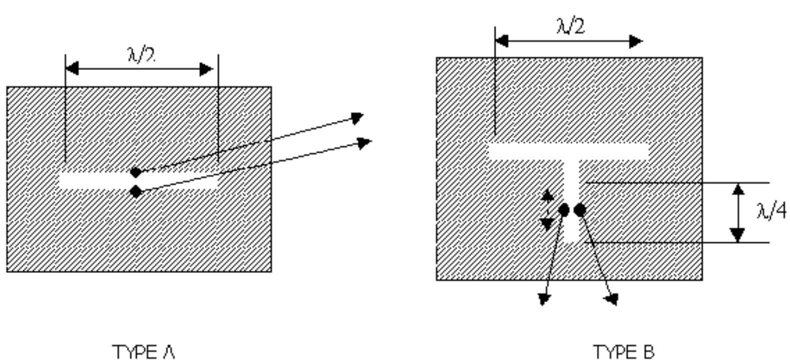
Ask New Question

A slot antenna is a slot in a flat piece of metal or other conductor. It can be thought of as sort of the complementary version of a dipole.

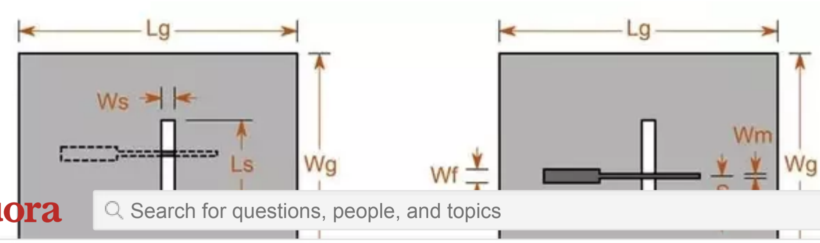
Rather than a 1/2 wavelength of centerfed wire in free space making up a dipole antenna, a dipole slot antenna is usually a 1/2 wavelength long slot in a large ground plane. It can be fed in a number of ways. One common way is to place slots in a waveguide. With the right placement and spacing, a number of slots can act as a directional and effective antenna. Or it may be a slot in the ground plane on a PCB with the signal fed to the center edges, often a bit off center to match impedances.

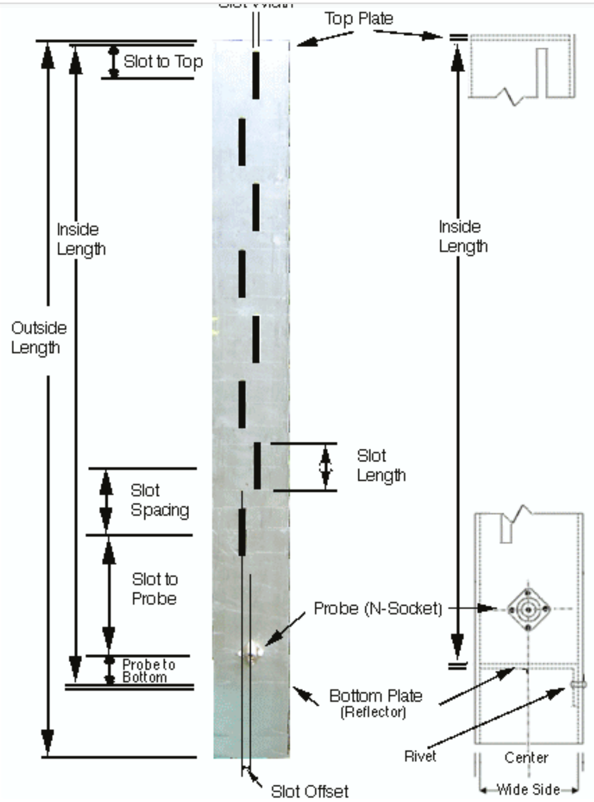
Whereas the polarization of a dipole antenna is the same as the orientation of the elements, a slot antenna has a polarization 90 degrees from the orientation of the slots.

Thanks to Paul Hills website at Homepages dot Which dot Net, as you can see it can even be fed with a 1/4 wavelength stub to match impedance just as you do with a dipole:

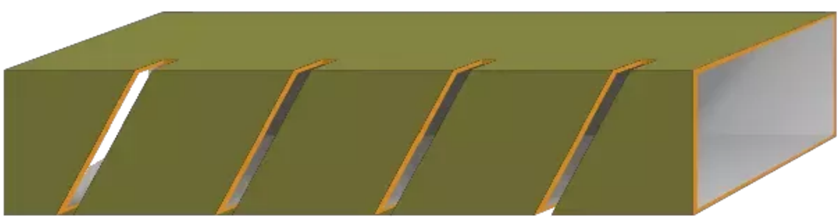


Thanks to Feko dot Info, note that it is fed slightly off center to match impedance and match an unbalanced feedline to a balanced slot antenna:



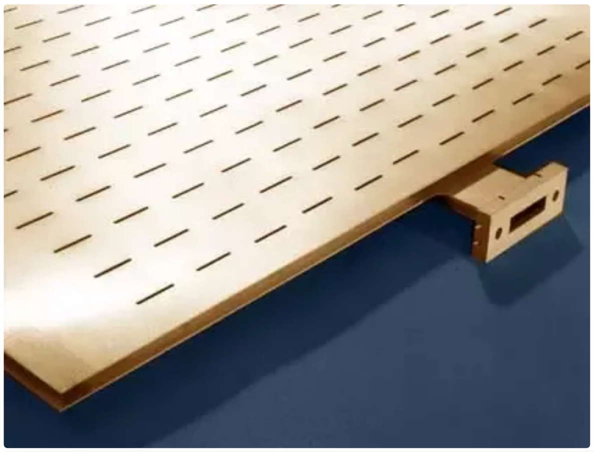


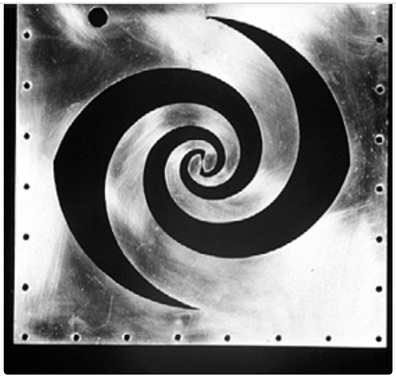
Thanks to RadarTutorial dot EU:



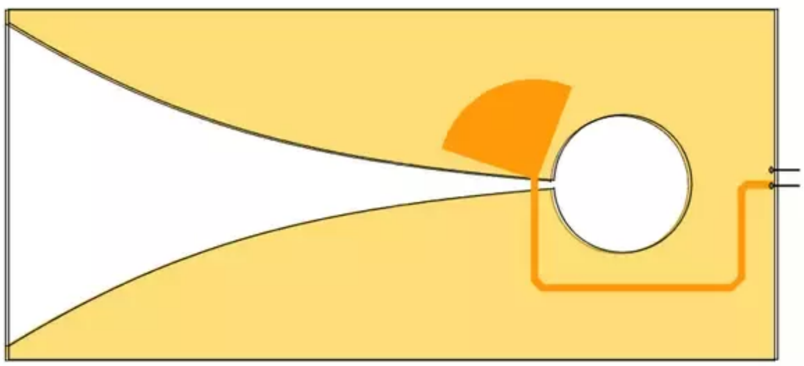
Wide arrays can be made to gain the chosen directionality.

Thanks to L-3 dot Com:

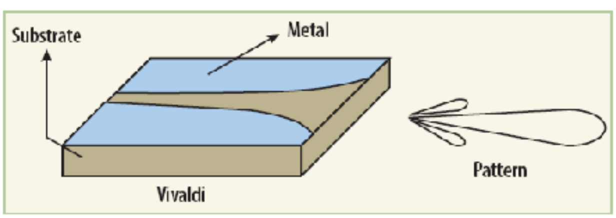




Here is a strange one. A Vivaldi slot antenna, aka tapered slot. The signal fires out of the left end of what you see here, is polarized in the orientation of the ground plane, and is fairly unidirectional and extremely broadband. The large pale part is part of a groundplane, the smaller darker part is one of many ways to make a broadband feed to this antenna. Thanks to RadarTutorial dot EU:

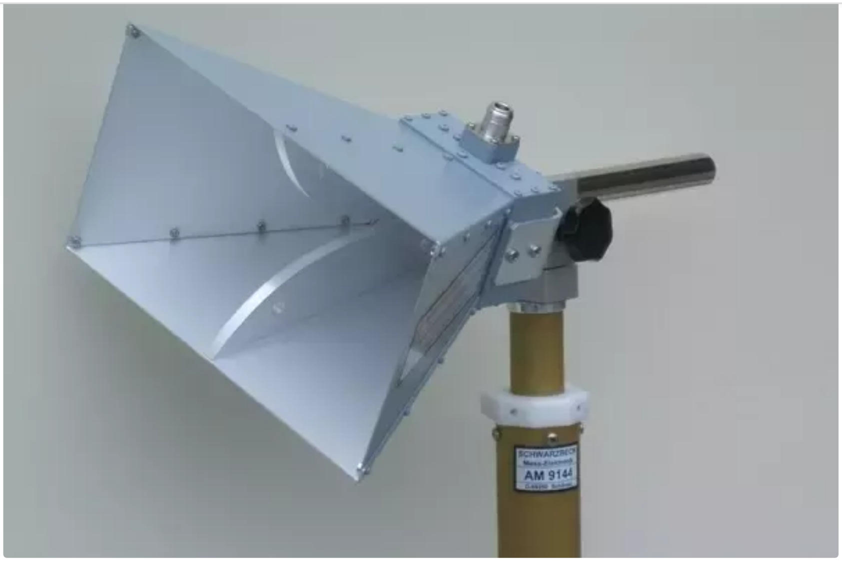


Thanks to MWRF dot Com:



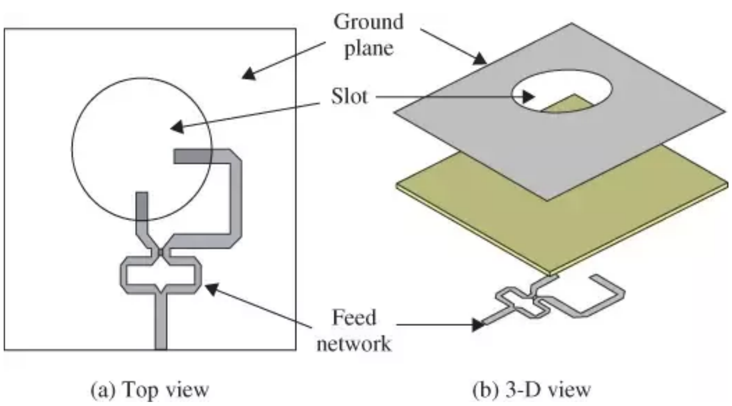
2. This plot shows the typical radiation pattern for a Vivaldi antenna (from ref. 8).

Thanks to Wikipedia dot Org for this combination of a Vivaldi tapered slot and horn antenna with remarkable bandwidth from 800MHz to 18GHz:



Some slot antennas look more like a complementary version of a patch antenna.

Here is a circularly polarized slot antenna that is a round hole fed with two feeds 90 degrees out of phase. Thanks to Download dot E-bookshelf dot DE:



Related Questions More Answers Below

What are the applications of the U-slot microstrip patch antenna?

What should be the shape of a patch antenna (rectangular or circular) in an UWB (ultra wide band) antenna?

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What is a microstrip patch antenna? What are its applications?

Ask New Question

A slot antenna is literally a hole within a plane, whereas a patch antenna is a separate medium on top of a plane. Slots can be used in low frequency apps, but patches work best at UHF and above.

Carmel Pule', former Diagnostician RN. Lecturer at at University of Malta (1956-2016)
Answered Dec 8

Before one explains what the question asks, for let us compare the solitary dipole antenna with the slot antenna, each of the same length. One may look at the dipole as a length of conductive material equal to half a wavelength, placed and surrounded by a large sheet of insulating space, if one considers one plane in which the dipole is placed. A slot antenna may be looked upon as a slot, half a wavelength in length housing some space which is surrounded by a large conducting sheet. If one places a dipole on top of a slot antenna one may imagine either having one sheet of conductor or else one sheet of space!.

In case of the half length dipole conductor antenna, when one excites it at its centre, along its length, what goes up and down along the length of the conductor and along the space to ground is the electric field loop and what goes around circling the upper and lower conductor in loops is the magnetic field. In the case of the slot of length half a wavelength, cut in a conductive sheet, this being excited at its centre, across the slot, the electric field will form across the slot and in the plane of the conductive sheet, while the magnetic field will circle the cross path at the centre across the slot where it will form loops in and along the slot on either side of the conductive sheet forming the two loops of a figure of eight, one loop on either side of the conductive sheet housing the slot. In fact in a slot, the electric field will replace the magnetic field in the dipole and the magnetic field in the dipole will replace the electric field in the slot.

Now if behind the dipole one puts a large conductive sheet, this would behave as a good reflector and what energy went in the direction of the conductive sheet, it will be reflected to go in the same direction as what the dipole radiated in the other direction. It is similar to having a filament lamp where one puts a reflecting mirror behind it. All headlights in cars use this philosophy to increase the light density in one direction and even make the light more directional than before. This is the realm and philosophy of directional antennas.

With a patch antenna above a conducting sheet, one may regard it as closing in and being equivalent to the dipole being positioned ahead of a reflecting conductive sheet. The patch has the advantage as being shaped in various shapes including being shaped as multiple dipoles arrays depending on the high

measurements would permit small antennas to be placed in a patch where one can even add a reflector behind it, all to arrange for a polarised directional antenna to be formed. Directional antenna arrays and even astronomical radio telescopes use this philosophy of arrays and their size is so large because of the relatively low frequencies being used. Patch antennas may only be used when the frequencies are very high and where small dimensions would have an advantage.

For efficient radiation and reception, slot antennas must always be cut at right angles to the current flow in the side of a wave-guide or the vertical stabiliser in an aircraft. Slot antennas have the advantage of being made streamlined in a flying craft, as dipole would have their disadvantages. Patch antennas are so small and they too could be incorporated in a streamlined manner with the structure of a high speed moving craft. While the dipole has been a faithful servant for the last one hundred years, the high frequencies being sought now made both the slot and the patch antenna a working proposition in many areas. Their design needs a ton of computer processing power to be able to predict their performance! Perhaps one might add that the dipole tried to stand its grounds by changing in to a shark shaped fin to be included in aircraft. One may philosophise a little and to think that most aircraft in the air and ships at sea are now patch antennas and they have to be designed with a non reflecting design for their safety, it becomes a bit of a paradox that we have to learn when a patch does radiate and when it does not!!

Tamara Wilhite, bachelor of science Industrial Engineering, The University of Texas at Arlington (1998)
Answered Dec 11

Slot antennas are easier to make and modify, though patch antennas can be nearly as cheaply made using printed circuit board production lines.

Slot antennas can send much more powerful signals.

You can build a slot antenna into a structure and put it somewhere others may not know it is.

The Pros and Cons of Slot Antennas

Related Questions

Why microstrip patch antennas have low bandwidth?
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Ask New Question

What are broadband antenna types?

+ Ask New Question

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Ask New Question

AWSH.ORG

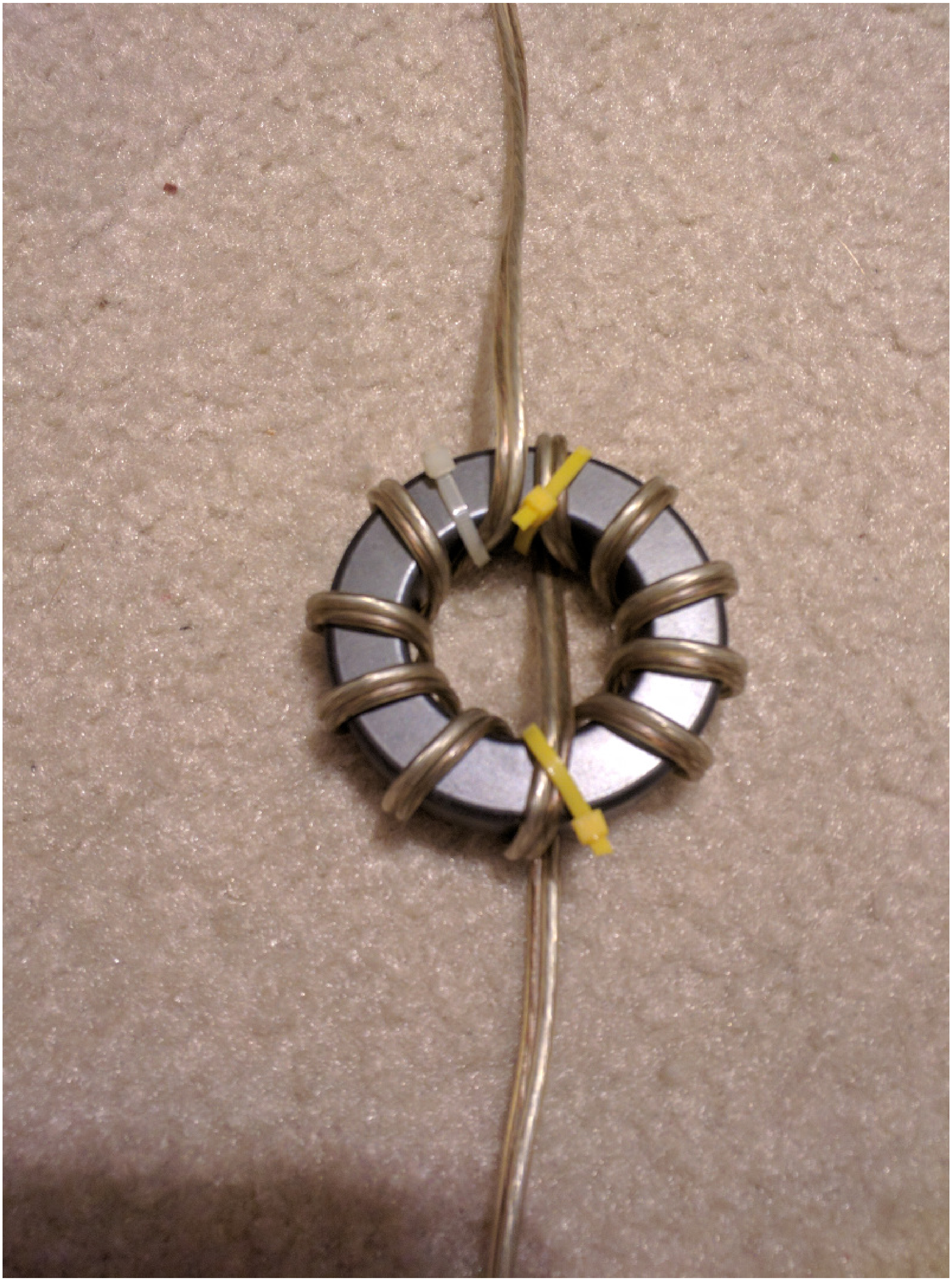
stuff that i do and things that i make

20m dipole upgrade

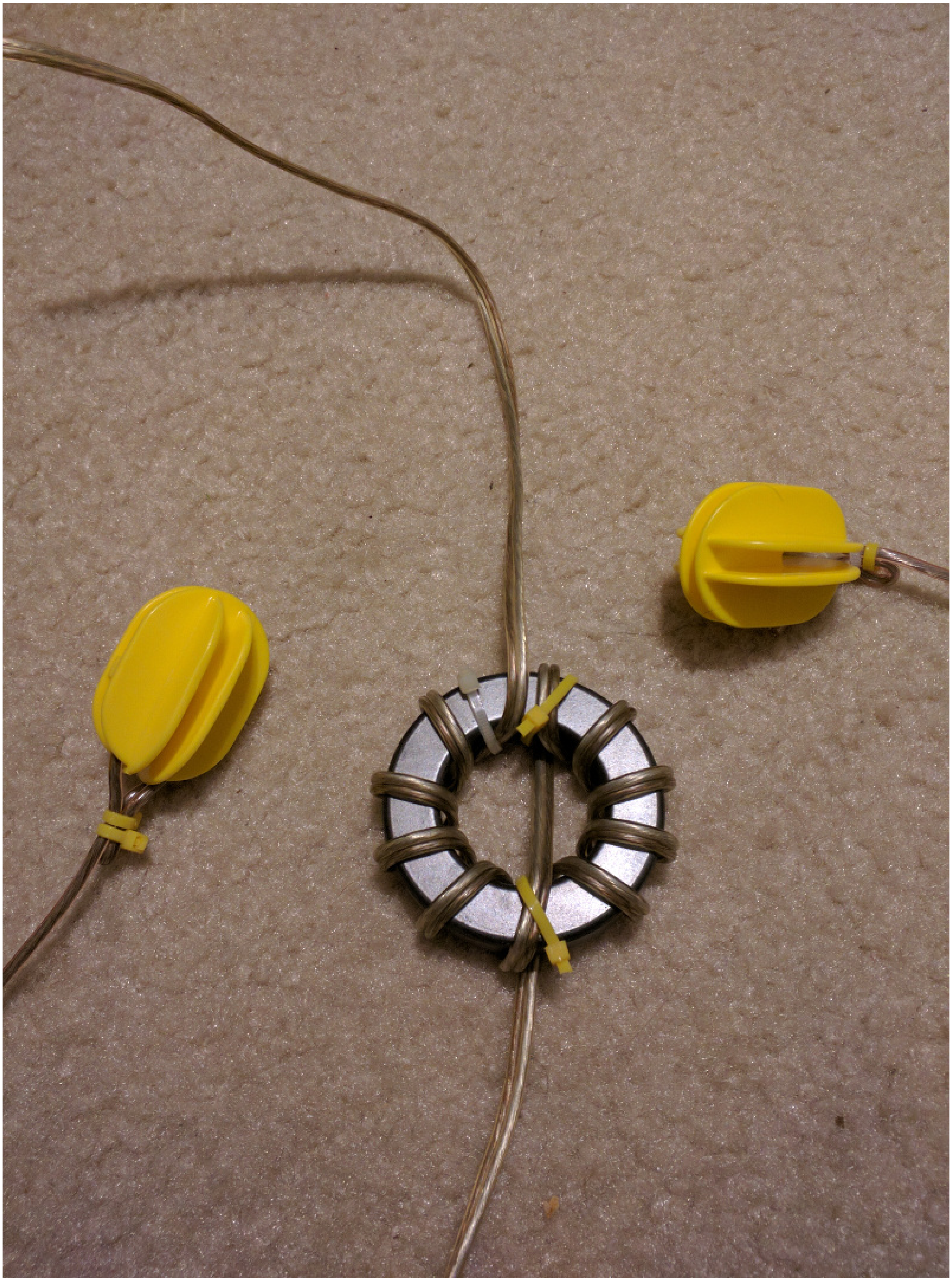
PUBLISHED DECEMBER 18, 2017

I haven't posted much in the last month or so, but I have been working on a few projects. One of them involves the 20 meter band and my quick attic antenna wasn't cutting it, so I put together a new one made from speaker wire.

I wound a proper balun on an FT240-43 and connected one end to the coax running down through the wall.



I used some electric fence insulators for the ends and I strung it up in the attic.



So far, it is working well.

PUBLISHED IN **ANTENNAS** AND **RADIO**

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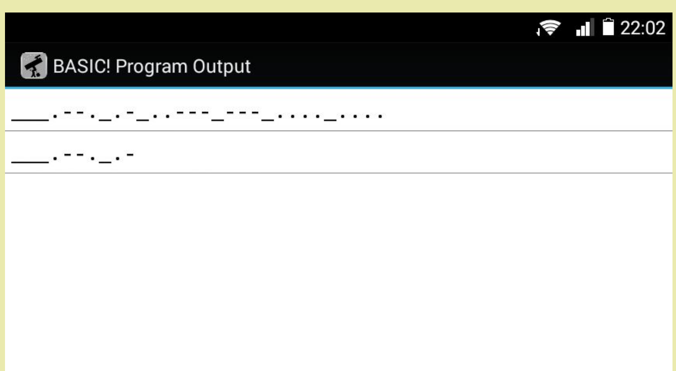
BEACON TRANSMITTER KEYED BY A SMARTPHONE

(2016)

KLIK HIER VOOR DE NEDERLANDSE VERSIE

The beacon transmitter is keyed by the audio output of a smartphone.

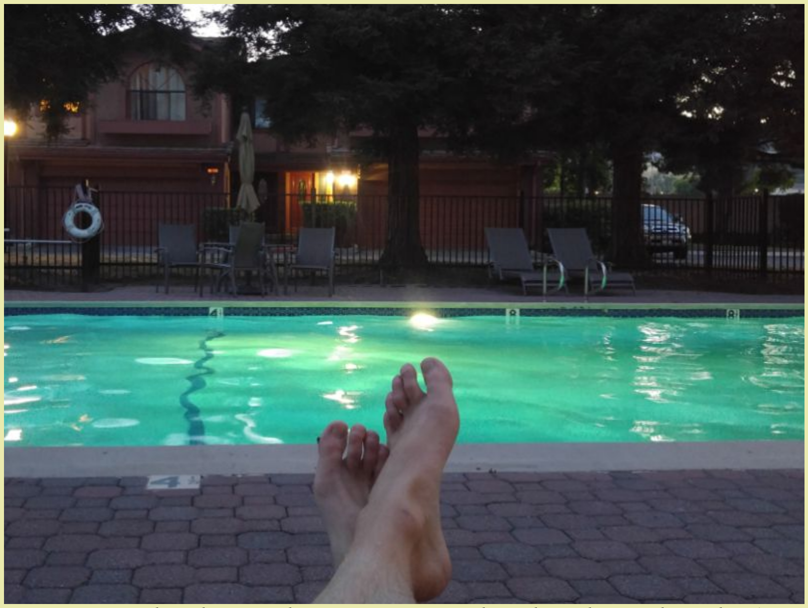
Experiments with very low power QRSS beacon transmitters
There is a group enthusiastic radio amateurs that is doing experiments with very low powers. That is possible by using a low CW speed (QRSS speed). Most of the activities can be found in a band of only 200 Hz, namely 10139.9 to 10140.1 kHz in the 30 meters amateur band. But nowadays, the transmissions are time synchronized. The transmissions start on multiples of 10 minutes. The reception is also started on multiples of 10 minutes. The advantage is that it is possible to stack received signals, a kind of addition of a number of received signals. And so the weak signal are better readable. This time synchronized transmission was not possible with the audio player, but it is with a smartphone! And because everyone always wants to have the latest smartphone, there are plenty of old smartphones available! A simple program was written in the free programming language RFO basic, as with RFO basic you can generate tones and thus make Morse code! Below is a screenshot of the smartphone in action.



Screenshot of the smartphone with the simple RFO basic program.

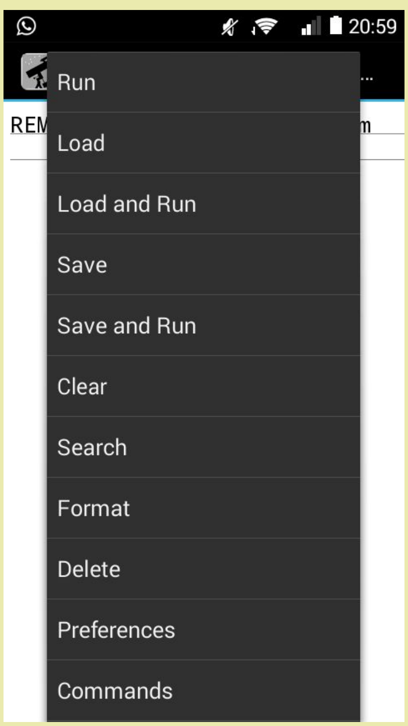
Hobby for lazy people?
Is it a boring hobby? Your smartphone keys your beacon transmitter and you do not have to do anything! Enjoy a relaxing weekend on bare feet, snow cleaning, to plant a tree or to read your favorite radio magazine in the garden and at the same time you are still busy with radio! You do not need your shoes and socks, unfortunately you have to stay at home, as it is not allowed that your beacon transmitter operates unmanned! Therefore, such a beacon transmitter is also known as a MEPT, a Manned Experimental Propagataion Transmitter. Perhaps that you can say that the whole world is your home, but I do not know if that is acceptable for the authorities.
What this hobby makes so interesting is of course where your weak signal will be received. Normal radio amateurs mention the standard 100 watt power already "Barefoot" power, because they think that it is the minimum usable power. But a MEPT is only 0.5 watts which is 200x lower. And I used only 10 milliwatts, so 10000x

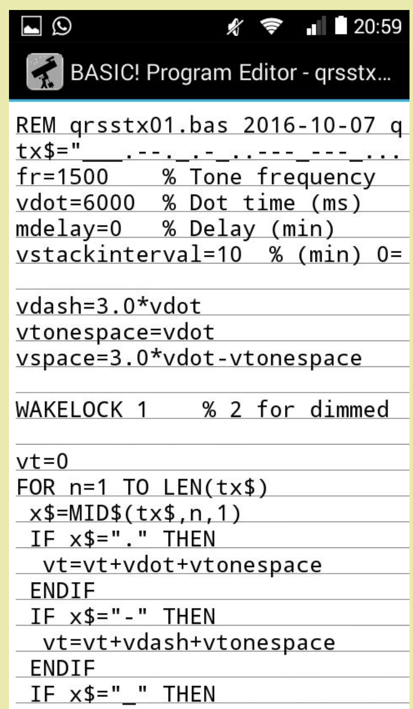
lower than the standard "Barefoot" power. Still nice that the 10mW can be received troughout whole Europe. Even a 1 mW signal can still be received at many places! And technically seen it is also a very interesting activity! It has to be possible to adjust the exact frequency of your MEPT with an accuracy of better than 5 Hz. For stacking, the drift should be less than 1 Hz per hour. And the transmissions have to be time synchronized. To make a reception station is also very challenging. But it can all be realized with simple, inexpensive means. It is indeed a very nice, cheap and little time consuming hobby!



Your smartphone keys your beacon transmitter and you do not have to do anything!

RFO basic
You can use RFO basic to create simple programs. RFO BASIC! is a dialect of DARTMOUTH BASIC that allows you to write and run programs directly on your Android device. And ... it's free! And easy! You can download it at the following website:
http://rfo-basic.com/
You can download and install the app here. But it is also possible to do that via the standard AppStore on your smartphone. You can also find here the documentation and manual. Nowadays we want to have a result as quickly as possible. But it's better and nicer to spend a few evenings to read the manual and to see what possibilities there are and to play a little with the sample programs that are included in the software.





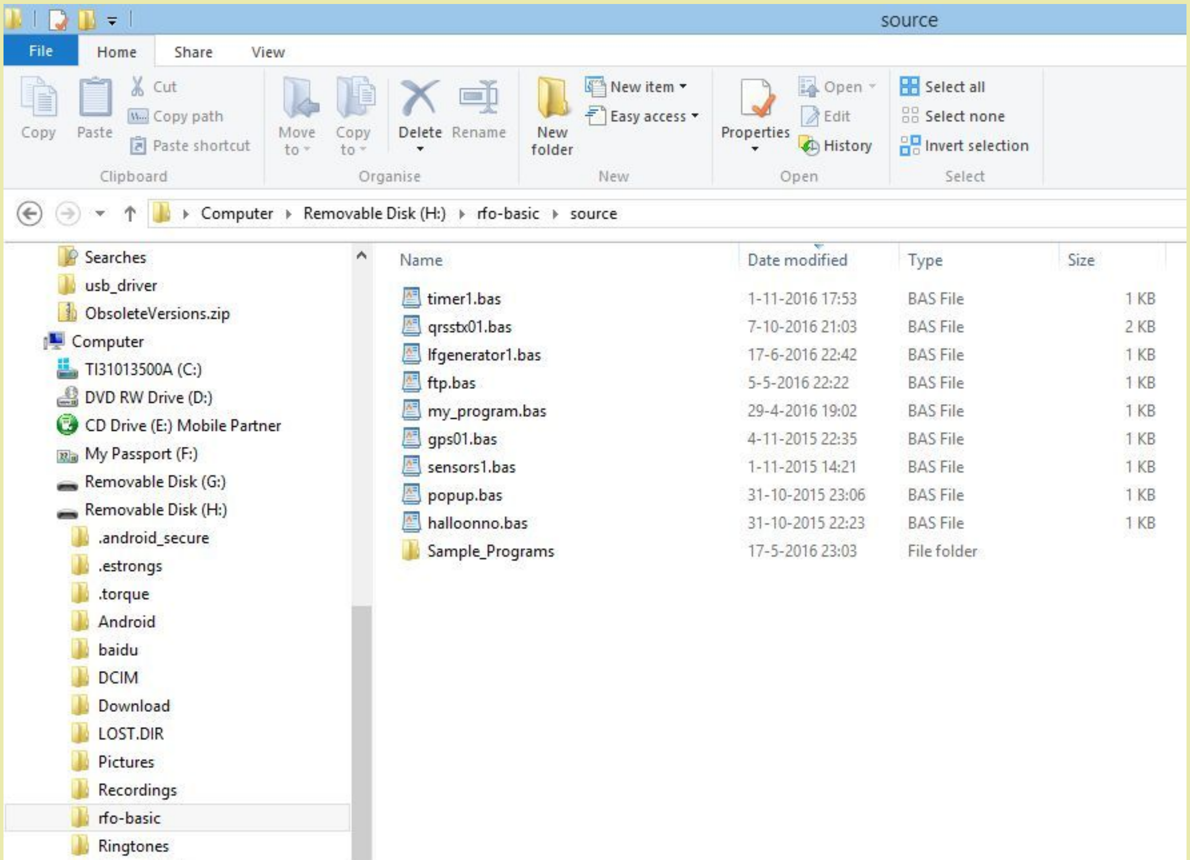
The menu of the developement environment of RFO basic and the program to key the beacon transmitter.

The menu is simple and a further explanation is not necessary. Apart from the normal basic functions, there are also many for the features of your smartphone. You can read the GPS data, read SMS messages, activate the buzzer or take a picture with the camera. For example, you can create a program that makes a photo every hour and uploads it together with your position to an FTP site.

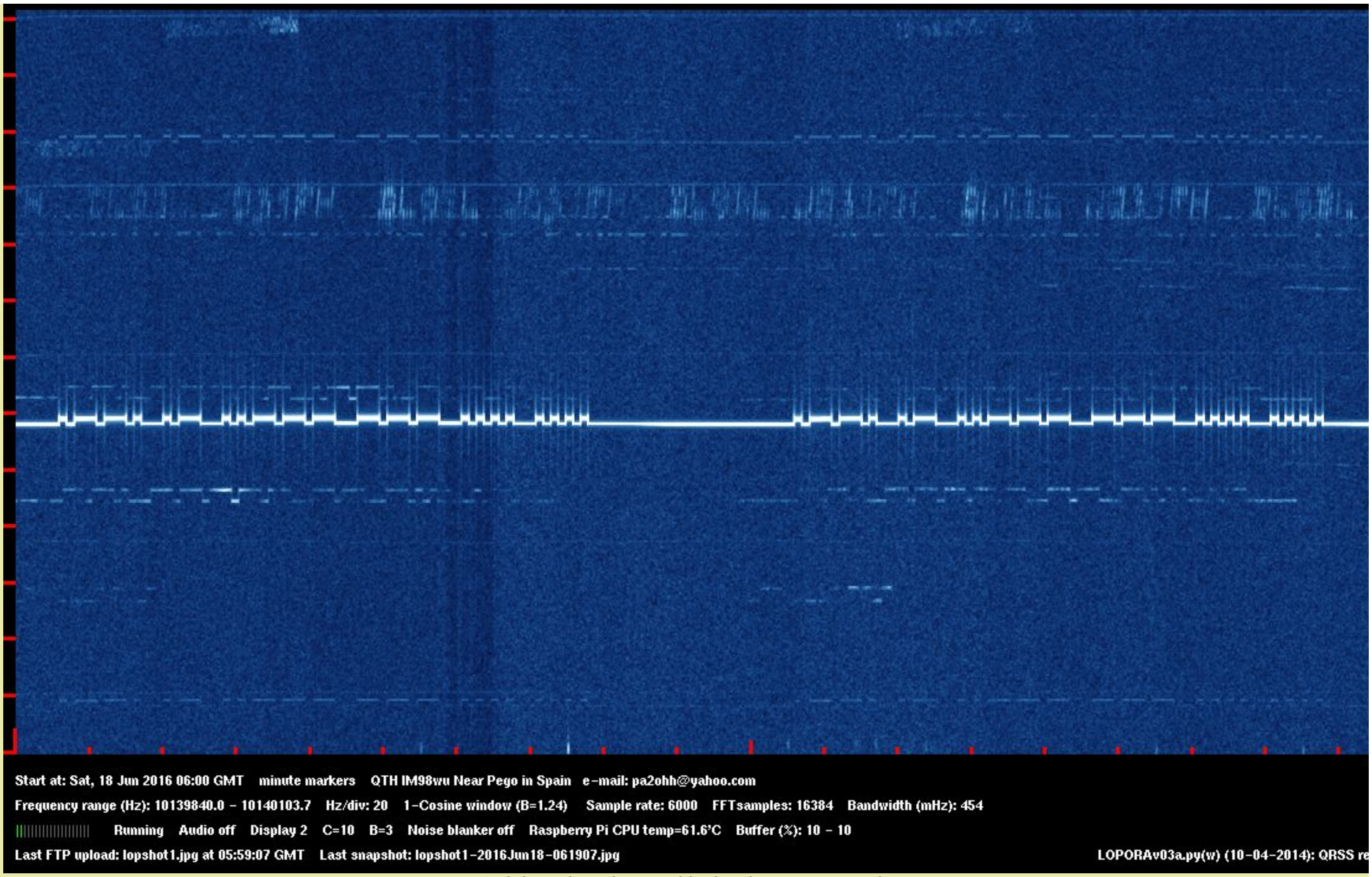
Download the RFO basic program by clicking the link here below:

- 16rfobesoft.zip

Besides the "qrsstx01.bas", the ZIP file also contains some other programs, the result of playing a few days with RFO basic.
Connect your smartphone to the USB port of your PC and upload the "qrsstx01.bas" to the directory "H:\RFO-basic\source". RUN RFO basic and select the program with the menu option "Load". Now you have to change a few lines of code:
The variable "tx$" has to be changed to your call sign in Morse code. An underscore is a pause between two letters.
The variable "fr" is the audio frequency and does not need to be changed.
The variable "vdot" is the time duration of a dot in milliseconds.
The variable "mdelay" is a delay and you can set it to 1 or 2 if you do not want to start exactly on multiples of 10 minutes but 1 or 2 minutes later.
And the variable "vstackinterval" is 10 for the standard synchronized transmissions on multiples of 10 minutes. You can also change it to 20 minutes or 30 minutes. When you set the value to zero, the transmission is not time synchronized.
Save the program and select the menu option "Run" to start the program.
Connect the headphone output to the beacon transmitter and set the volume to maximum. As the output only has to give voltage and no power, this will not cause any problems.



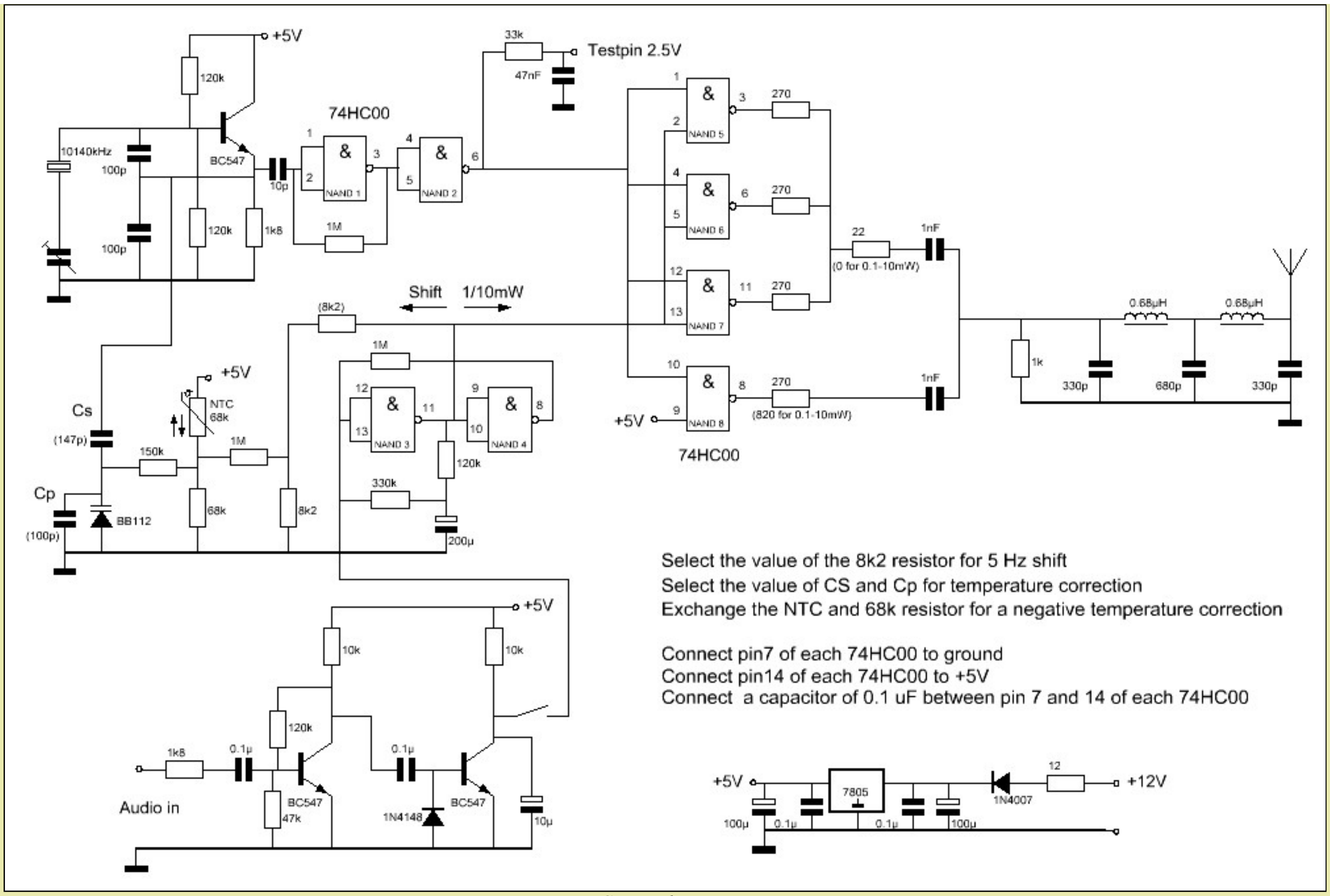
Connect your smartphone to the USB port of your PC, the program can be found in the directory here above.
In the directory Sample_Programs you can find all kinds of interesting example programs.



And this is how the signal looks when it is received.

Now let's look at how you could make the hardware. There are of course other possibilities, this is my MEPT of only 10 mW.

Description of the circuit diagram of the transmitter
A crystal oscillator with a BC547 transistor is buffered by NAND1 and NAND2 and amplified by NAND5 to 8. The circuit with NAND3 and NAND4 is a square wave oscillator. When the switch is opened, the transmitter is frequency modulated by this square wave. But also in amplitude. During the positive half of the square wave, NAND5 to 8 are all switched on and the transmit power is 10 mW. During the negative half of the square wave, only NAND8 is active and the transmit power is only 1 mW (or 0.1 mW, depending on the used resistor values). When the switch is closed the transmitter is keyed by the audio signal of the smartphone. The left BC547 does amplify this signal, the right BC547 with diode 1N4148 is the detector that makes zeroes and ones out of it. The capacitor of 10 uF does suppress the audio and other interferences.
During the transmission of a dot or dash, the transmit power is 10 milliwatt. During spaces, the transmit power is 1 milliwatt (or 0.1 mW, depending on the used resistor values) and the transmit frequency is lowered with 4 to 5 Hz. But for the current experiments, the beacon does transmit both shifts with 10 mW. The NAND's are all connected to +5V instead of to the output of NAND3.

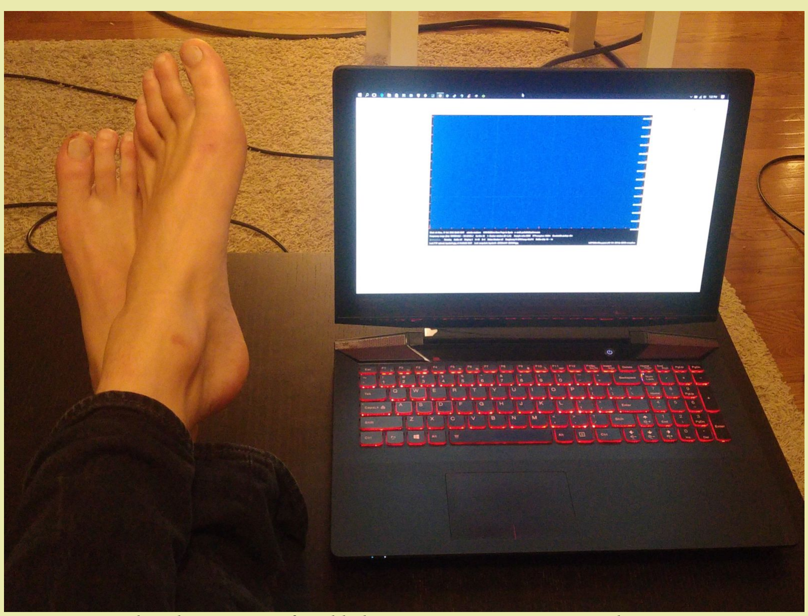


Circuit diagram

big diagram

Temperature stabilization

The frequency has to be very stable. It is quite difficult to adjust the beacon transmitter on a frequency of 10139.9 tot 10140.1 kHz and to avoid drift due to temperature changes. A temperature correction circuit was made with a NTC resistor and a varicap. The drift could be reduced considerably. For a positive frequency drift correction, you have to connect the NTC in accordance with the diagram. For a negative correction, the NTC resistor and 68k resistor have to be exchanged. Of course you can also take a NTC resistor with a different value. Exchange the 68k resistor then for one with the same value as the NTC. Increasing of Cs and reducing Cp increases the correction, reduction of Cs and and increasing of Cp does reduce the correction. Finding the correct value is a question of trying out while cooling down and warming up the transmitter with various values of Cs and Cp. Between 5 and 35 °C, the temperature drift is only 4 Hz.



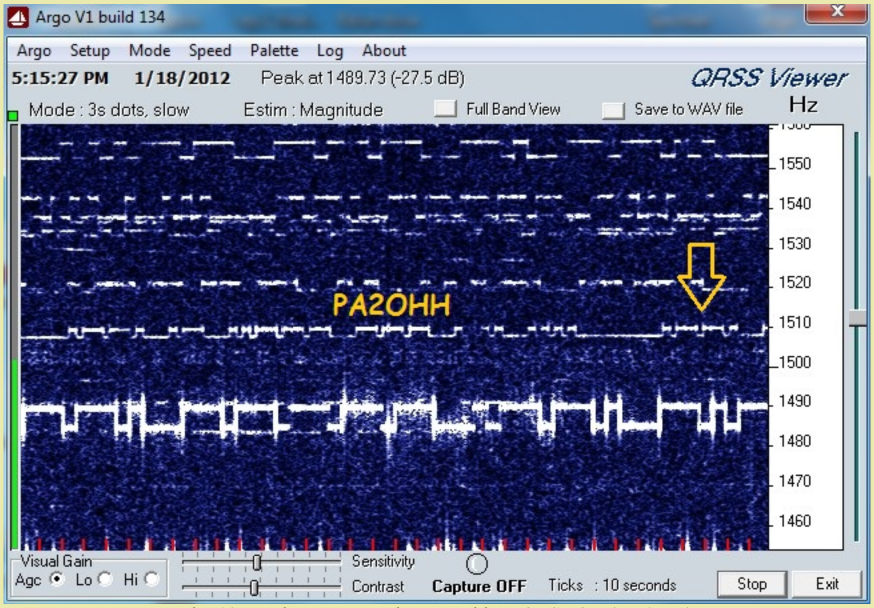
Relaxed in your comfortable living room you can use your laptop or tablet PC to look at the reception results on the internet!

How do you know where your MEPT is received?

Sometimes you get an email with a reception result. But there are also other possibilities to get reception reports. And that is even possible while relaxing barefoot in your comfortable living room lying in front of the TV with your laptop or tablet PC. There are amateurs who have connected their reception station to the internet. The reception results are refreshed every few minutes. These results can be viewed on the internet, such a receiving station is called a grabber (Search Google for "QRSS

grabbers"). There are amateurs who have made lists of available grabbers. Search for "QRSS grabber compendium" or "QRSS grabber aggregator", that of Scott Harden is a very good one, it shows the active grabbers and also the stacked images and an archive of the last received results.

Enjoy a relaxing weekend, you outdoors at work on your bare feet and your MEPT indoors at work with minimal "Barefoot Power", how harmless and peaceful life can be. During all kinds of other activities around your home you are still busy with radio at the same time, as there are always moments to look at the grabbers! In the garden at work, have a look at your tablet PC in the garage so now and then. Snow cleaning, look at the grabbers on your new smartphone so now and then. Oops, COLD...



The 10 mW beacon signal received by YO7CKQ - (KN15pa).

The 10 mW beacon signal received by the grabber of IK1WVQ - MAURO (JN44cb).

The 10 mW beacon signal received by the grabber of SA6BSS (JO68sc).

And if you do not have time to look at the grabbers, there are also programs (QRSS Archiver) that download and collect the results of the grabbers for you download so that you can see them later. See for example "http://www.qsl.net/g0ftd/seqdownload.zip"
With RFO basic you can also download images? Another idea for a new program, a QRSS Archiver with RFO basic! And with RFO basic you can also do FTP uploads and downloads. Can I switch the MEPT remotely on and off with it around the whole world? Then the world is really my home! All kinds of new ideas!

And if you want a very easy way to make a MEPT, you can buy a kit for a MEPT and a GPS module so that you always transmit on the exact frequency and do not require a smartphone, for example the Ultimate3S: QRP Labs Multi-mode QRSS Beacon Kit.

BACK TO INDEX PA2OHH

The Hendricks QRP Kits
SMK-2 Construction Manual

A Learning Tool For Surface Mount Construction Kit Building

By Dave Fifield, AD6A
Revision 1.9
April 2012

WARNING – DO NOT OPEN ANY OF THE PARTS BAGS YET!

If you really must skip the introduction - be sure and read the section titled "Don't Open the Parts Bags Yet" at the top of page 3 BEFORE you start!

The SMK-2 Construction Manual

Introduction

Thank you for buying a Hendricks QRP Kits SMK-2 kit. We're sure you will enjoy learning/practicing surface mount construction techniques by building the SMK-2. As a bonus, when built, the SMK-2 is a fully working 40m CW transceiver that you will be able to use on the air to make contacts!

The idea to produce the SMK-2 kit came from Doug Hendricks, KI6DS, who thought it would be a good idea to have a cheap learning tool to get hams used to doing surface mount construction, since that's the way virtually the whole electronic industry has gone and will inevitably become the technique of necessity for ham kits in the future. It was first kitted by the NorCal QRP Club known as the SMK-1. It was a board only kit at that time.

Red Hot Radio was purchased by Hendricks QRP Kits in December 2011, and the decision was made to update the SMK-1 by adding a case and making a small circuit change to improve the performance. The updated kit also uses two 3 pin female SIP strips as crystal sockets. This will allow crystals to be changed easily. The Hendricks QRP Kit will ship with both 7.030 and 7.040 crystals, hence the name SMK-2.

Everything you will need to turn the SMK-2 into a fully working rig is included in the kit. The custom case was designed by Ken LoCasale, WA4MNT, and is an addition to the original SMK-1 kit.

The SMK-2 contains over 80 components. Most of them are surface mount parts. Some parts, like crystals, trim caps and pots, are either too expensive or not easily obtained in surface mount packages, so through hole parts are used.

The surface mount parts used in the SMK-2 were chosen to be large enough for most hams to be able to handle them with a small pair of tweezers and solder them in place using a fine-tip soldering iron. They are not the smallest surface mount parts by a long way, but they are small. I have personally built several kits now without using a magnifier, but I do recommend you use one if you have one! It will make life a lot easier for you, especially if your eyesight isn't quite what it used to be!

I recommend that you use a 1/16th inch or smaller soldering iron tip, preferably temperature controlled, and use 0.020" silver solder (although just about any solder will do!).

You will need a small pair of angled tweezers to handle the components with dexterity and without damage.

Have fun building your SMK-2 kit – please let us know your progress and give us your comments/feedback on the QRP-L email reflector.

General Description

The SMK-2 circuit is basically a modified Tuna Tin 2 transmitter integrated with a modified MRX-40 receiver. It is a further modification of the modified TT2/MRX-40 that I built for the indoor foxhunt at Pacificon 1999. All this is fitted onto a small 2.475" x 2.25" PCB.

The transmitter consists basically of the two 2N2222A transistor lineup of the original TT2 but with electronic keying. A key-switched crystal oscillator that has some degree of VXO feeds a medium power packaged version of the 2N2222A as a final in class A mode. After harmonic filtering, the result is about 350mW of fairly clean transmitting power on 7.030MHz (+/- a bit).

The RX front end uses the ubiquitous NE602 mixer/oscillator with a crystal VXO. The RX is a direct conversion receiver, so you will hear both sidebands as you tune through a station.

The audio output of the NE602 direct conversion front end goes through a FET switch that serves to mute the audio to an acceptable side tone level during TX and then on to a standard LM386 audio power amplifier running as much gain as it can.

The three controls on the front panel of the SMK-2 are (left to right as you look at it): RF attenuation, RX tuning, and TX tuning. Operating the SMK-2 requires a little knowledge of where you are receiving and transmitting – there will be more on this in a later section of this manual.

Don't Open The Parts Bags Yet – MUST READ!

The kit contains mostly surface mount parts. Before you open the parts bag, please understand how you will identify them. The resistors are marked with a number code. A 222 means 2.2K resistor, etc. They are listed in the manual and on the parts list. **The capacitors are not marked.** We have used a color code for them, and the color code is listed in the manual and on the parts list. The transistors and diodes are also color coded, and the key is in the manual and on the parts list. The inductors are also marked; the key is also in the manual and on the parts list. Make sure that you pay attention and install the correct part. Do not take a part out of the carrier until you are ready to install it.

The through-hole parts and the transmit output transformer are fitted last. Save the crystals, pots and trim caps till the end before you solder them in – it will make life much easier.

Missing/Defective Parts

We have made every effort to insure that all parts are included in your kit. However, due to the nature of the small surface mount components in the kit, it is very easy for you to lose parts and we anticipate that there will be some loss! Hendricks QRP Kits will replace parts for no charge, but you will need to send a self-addressed stamped envelope. Send your lost parts requirements to:

Doug Hendricks, KI6DS
862 Frank Avenue
Dos Palos
CA 93620
USA

Please include an SASE for the parts.

Technical Support

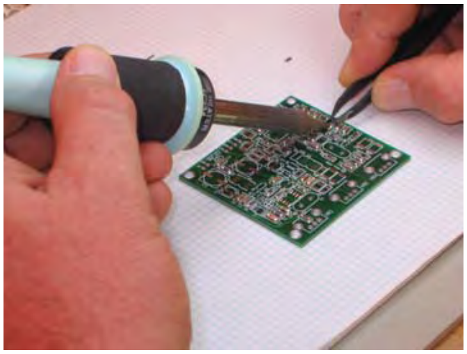
For complex problems or issues or if you don't obtain satisfaction from the QRP-L email list, please email me at ki6ds@qrpkits.com

Surface Mount Soldering Technique

Use a fine soldering iron tip (1/16th inch or less) at about 700°F if possible. Use fine solder (0.020"), silver solder if you can get it.

First, tin one PCB pad of the component you are going to solder down. Don't overdo the amount of solder – just a slight bump of solder is enough – maybe a ¼" of solder from your reel.

Next, pick up the component you are going to solder down using your tweezers – carefully, lengthwise – make sure you have it firmly, but not so firmly that it goes "ping" and flies across the room! With your soldering iron in one hand and the tweezers with the part in the other, carefully place the part down onto the pads in position – take care to line it up straight. Quickly dab the wetted soldering iron onto the lead/pad that you tinned previously to get it to stick nicely and sit flat.



Re-flow the solder on this pad if you need to adjust the position of the component. You must get it straight and/or symmetrical across the pads at this time – once you solder another pin, you will have no chance to re-position it at all.

Once you are happy with its alignment on the pads (try to get it right first time to minimize the possible heat damage to the component), solder the other lead/s down carefully. Go back and touch up the first lead if necessary. That's it – simple!

If you need to remove a part for any reason, the best method is to use two soldering irons at once, one on each end. If you only have one iron, add solder to both sides of the part and heat them alternately until the part comes away on the tip of the soldering iron. You will need to use some solder wick to clean the PCB pads before soldering down a new component. Surface mount components that have been removed by this method are usually good candidates for the trash can – try not to reuse them unless you really have to.

Getting Started

STEP 1: Capacitors

Using a pair of scissors, cut open the parts bag containing the capacitors. This is the one with white parts marked with different colored ink. Use the pictures on page 9 to help separate and identify the capacitors. Install them in this order:

- □ 1. 13 x 0.1uF caps. They will all be in a strip. They are marked with a black stripe. Remove and install one at a time at C3, C6, C7, C8, C10, C13, C15, C17, C19, C21, C22, C23, and C28.
- □ 2. 3 x 82pF caps. They are marked with a blue stripe. They go at C1, C5, and C25.
- □ 3. 1 x 100pF cap. It is marked with a brown stripe. It goes at C18.
- □ 4. 2 x 270pF. It is marked with a red stripe. They go at C4, C20.
- □ 5. 1 x 390pF. It is marked with an orange stripe. It goes at C24.
- □ 6. 2 x 470pF. They are marked with a yellow stripe. They go at C2 and C26.
- □ 7. 1 x 1000pF. It is marked with a green stripe and goes at C16.

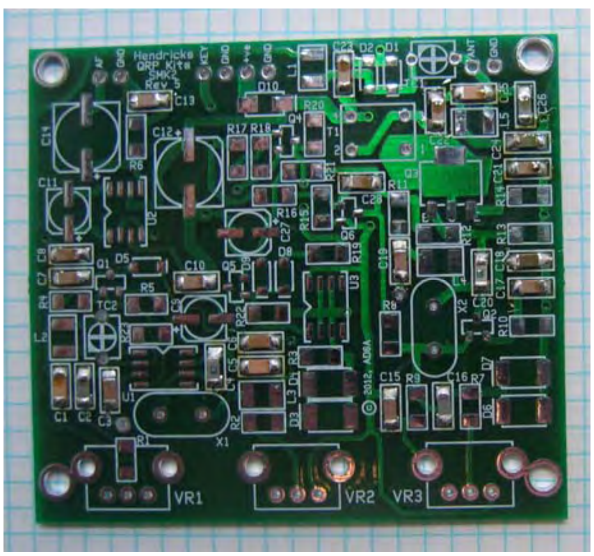


Fig. 2 shows the board after installation of the capacitors in STEP 1.

STEP 2: Resistors

Next we will install the resistors. Open the section of the bag with the resistors, and separate and identify them using the picture on page 9 as a guide. Again, open one component at a time and install as soon as you open the part. Install as follows:

- □ 1. 1 x 10 ohm, marked 100 or 10R at R6
- □ 2. 1 x 47 ohm, marked 470 at R1
- □ 3. 1 x 56 ohm, marked 560 at R14
- □ 4. 1 x 100 ohm, marked 101 or 100R at R11
- □ 5. 1 x 220 ohm, marked 221 at R10
- □ 6. 1 x 560 ohm, marked 561 at R15
- □ 7. 2 x 1K ohm, marked 102 at R13, R18
- □ 8. 2 x 2.2K ohm, marked 222 at R21, R22
- □ 9. 1 x 3.3K ohm, marked 332 at R16
- □ 10. 1 x 4.7K ohm, marked 472 at R9
- □ 11. 1 x 5.6K ohm, marked 562 at R20
- □ 12. 1 x 8.2K ohm, marked 822 at R12
- □ 13. 5 x 10K ohm, marked 103 at R2, R3, R7, R17, R19
- □ 14. 1 x 47K ohm, marked 473 at R8
- □ 15. 1 x 1M ohm, marked 105 at R4
- □ 16. 1 x 2M ohm, marked 205 at R5
  [R23 is not used.]

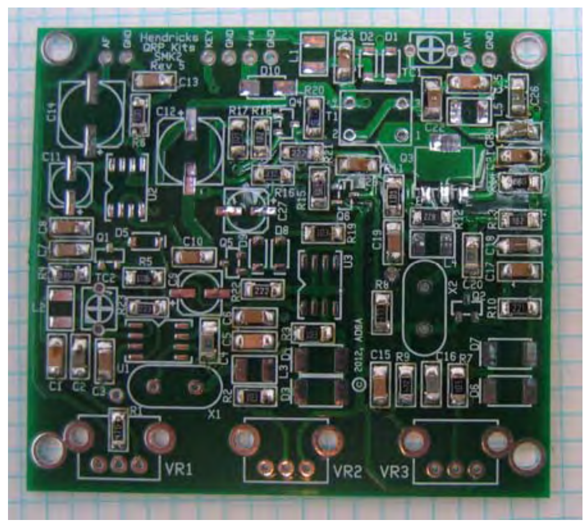


Fig. 3 shows the board after installation of the resistors in STEP 2.

STEP 3: Diodes

Now we are ready for the diodes: Open the diode section and identify the diodes by how many are in a strip. Make sure you align the bar ends of the diodes with the bar marked on the PCB legend before soldering them down.
Install in the following order:

- □ 1. 4 x 1N4004, marked GF1G at D3, D4, D6, D7
- □ 2. 1 x 1N5818, marked SS16 at D10

□ 3. 5 x 1N4148, marked A2YN or RLS4148 at D1, D2, D5, D8, D9

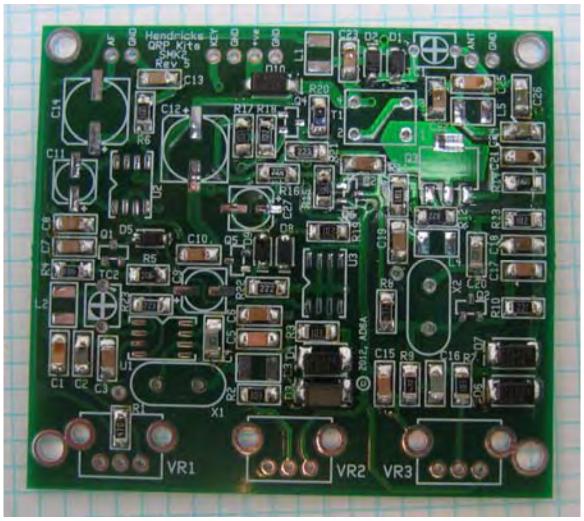


Fig. 4 shows the board after installation of the diodes in STEP 3.

STEP 4: Inductors

The next components are the inductors.

□ 1. 1 x 1uH, marked 1R0J at L5
□ 2. 1 x 4.7uH, marked 4R7J at L2
□ 3. 1 x 12uH, marked 120 at L1
□ 4. 1 x 22uH, marked 220 at L4
□ 5. 1 x 27uH, marked 270 at L3

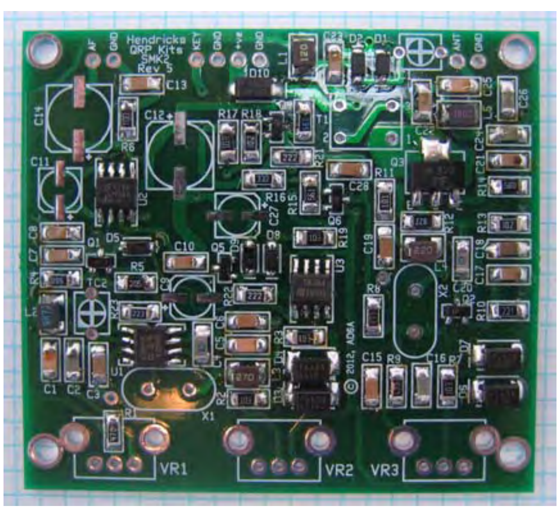


Fig. 5 shows the board after installation of the inductors in STEP 4.

STEP 5: Transistors

Next we do the transistors. The transistors are identified by a color code.

□ 1. 3 x MMBF2222AL, marked with a green color at Q2, Q4, Q5
□ 2. 1 x MMBF3906LT1, marked with a red color at Q6
□ 3. 1 x MMBFJ309LT1, not marked, has a clear plastic over the package. Install at Q1
□ 4. 1 x PZT2222A marked with R98 or RN8 P1F at Q3

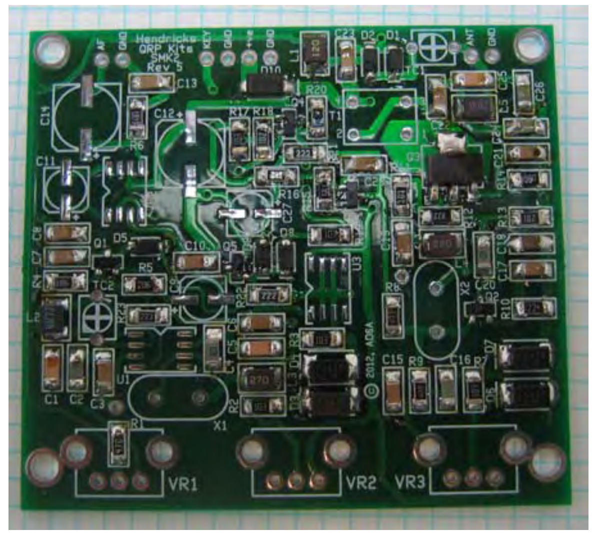
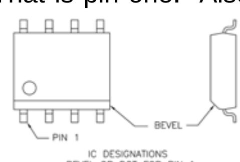


Fig. 6 shows the board after installation of the transistors in STEP 5.

STEP 6: Integrated Circuits

Now the IC's. To identify pin one on the 8 pin SOIC chips - locate the LM386 chip. You will note a small indentation or dot in one corner. That is pin one. Also, note that the edge of the IC is beveled on that side. That indicates the side with pin 1. Use this information to find pin 1 on the SA602 and the L78L06 chips. Be careful to place them correctly.



□ 1. 1 x SA612AD, marked A602A at U1
□ 2. 1 x LM386M-1, marked LM386M-1 at U2
□ 3. 1 x L78L06CD, marked 78L06 at U3

Fig. 7 on the next page shows the board after installation of the integrated circuits in STEP 6.

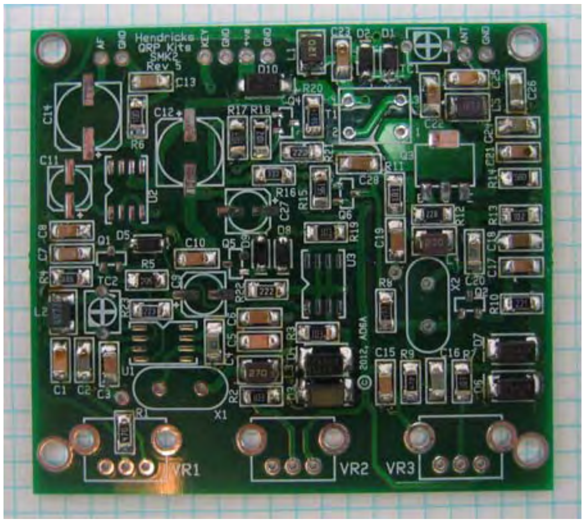


Fig. 7 integrated circuits

STEP 7: Electrolytic Capacitors

Next, locate the 1uF, 10uF and 100uF capacitors. The electrolytic capacitors are polarized. All of them have a one side painted black. This is the negative end and should be at the opposite end from the + symbol that's marked on the PCB legend. Solder them in place on the PCB paying careful attention to the polarization.

Pay careful attention to the alignment of all the polarized components or your kit will not work!

- □ 1. 1 x 1uF electrolytic, marked 1 50A or 1 50S at C9
- □ 2. 2 x 10uF electrolytic, marked 10 16A or 1 16S at C11, C27
- □ 3. 2 x 100uF electrolytic, marked 100 16S at C12, C14

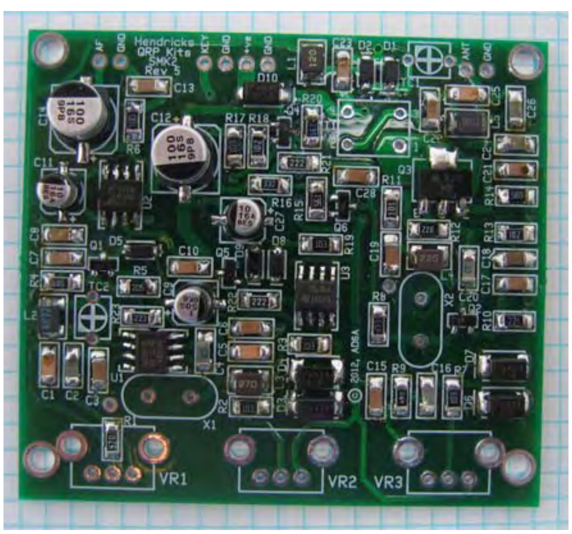


Fig. 8 shows the board after installation of the electrolytic capacitors in STEP 7.

STEP 8: TX Output Transformer (T1)

The output transformer is bifilar wound on the toroid. It is quite easily done. Take the toroid and the two pieces of red and green wire. Hold the two pieces of wire parallel and wind 6 turns on the toroid, counting one turn each time you go through the toroid. When you finish, prepare the ends of the wire by trimming them about 1 inch long at first. Then burn the insulation off to the edge of the core, use a piece of sandpaper to get all of the insulation off and make sure that you have bright copper wire showing. Tin each of the four leads. Now, trim each of the leads so that they are ¼" long. Solder the toroid in the holes on the pads, making sure that you solder the red leads to pads 1 & 2 and the green leads to pads 3 & 4. You must do this correctly.

STEP 9: Crystal Sockets:

You will find two 3 pin SIP strips in your kit. On each one, clip off the center pin with a pair of side-cutters, and now you have a crystal socket. Solder in the crystal sockets at X1 and X2.

STEP 10: Pots and Trimmers

Next, solder in the pots. Make sure that they are fully seated to the board. This is important when you mount your SMK-2 in its case

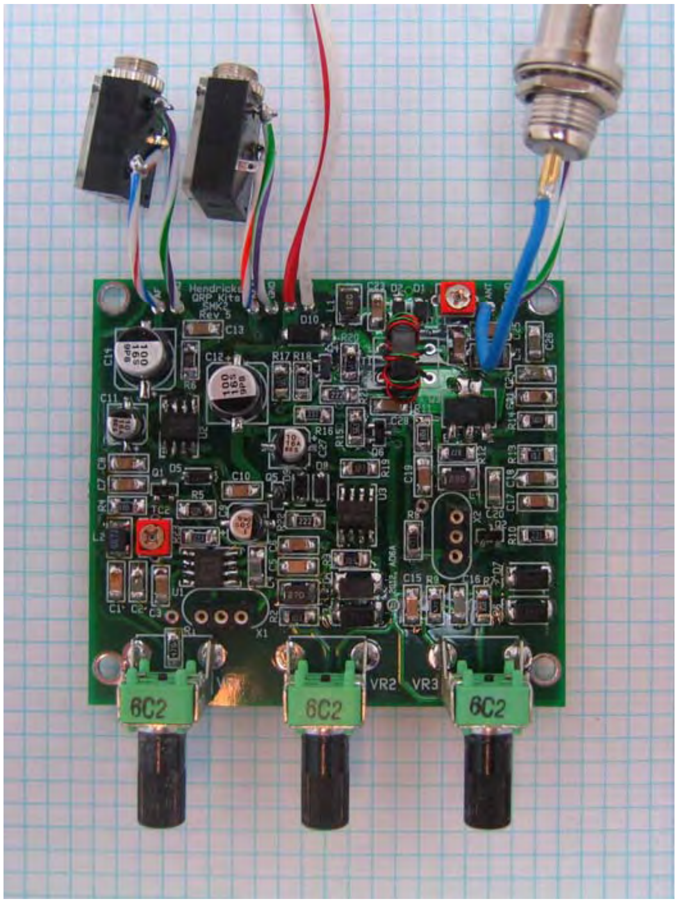
Finally, solder in the two trim caps. They are the little square orange devices from Bag #2. When you solder them in, make sure that you orient them exactly as shown on the silkscreen of the board.

STEP 11: Wiring Up

Wiring the connectors is simple. Use small gauge stranded hookup wire and connect the speaker jack, key jack, power jack and antenna jack of your choice to the back of the board as shown in the picture below.

STEP 12: Testing

Now it is time to test your efforts. Attach a dummy load. Then apply 12 volts. Check for smoke. (Hopefully there won't be any!!) Replace the dummy load with an antenna. We will start with the receiver section. Plug in a set of headphones. Peak TC1 first to make sure that you have 2 peaks. Go for highest noise level or signal. Next peak TC2 for loudest signal. Next is the easy part; the transmitter. Plug in a key, and transmit. Monitor on another receiver to make sure that you are putting out power.



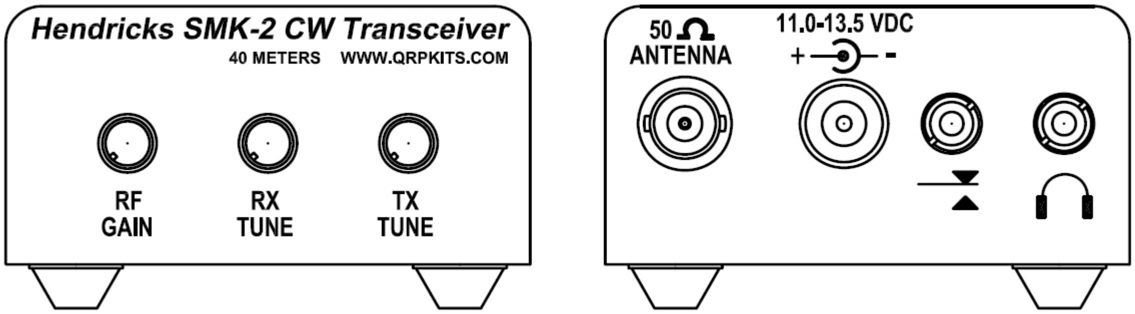
If you have problems, go to QRP-L, and post your problem. There are literally thousands of fellow QRPers there who will be more than happy to help with your problem.

FINAL STEP: Operation

Test units of the SMK-2 have tuned just below the marked crystal frequencies. The amount of VXO range varies with different crystals and component tolerances. Test units varied 1000-4000 Hz on the receiver and 200-1500 Hz on the transmitter. Thus the transmitter is the limiting factor on making contacts. Use a transceiver to verify which side of your signal that you want to tune the receiver to. You will soon learn that a dc receiver has two sidebands, and that you want to be on the correct one to make contacts. Verify the correct sideband on a transceiver, and then note which way that you tune the receiver in relation to the tone, (whether it goes up or down in pitch as you tune). Don't worry; you will soon get the hang of it. If you have questions, again, get on QRP-L, someone will be there to assist you.

Again, the purpose of this kit was to assist you in learning how to work with surface mount parts. We believe that it succeeds, and for a very modest cost. The transceiver does work, and it is capable of making contacts. It is not an ICOM 706 by any means though.

SMK-2 Decal install and finish assembly

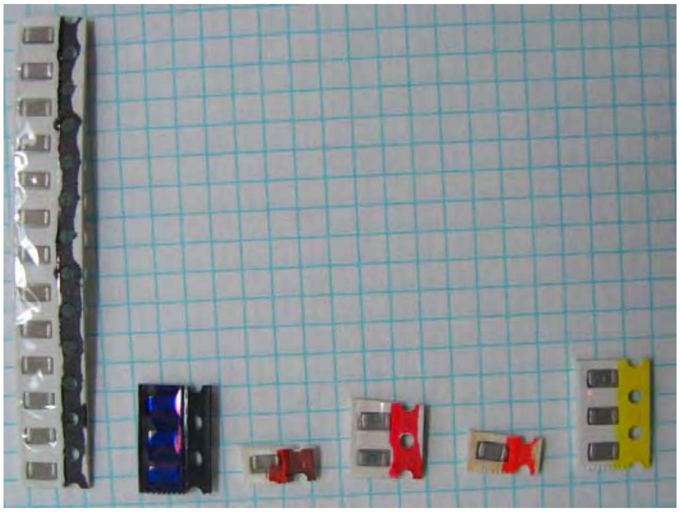


Thoroughly clean the surface of the panel to remove any oils or contamination. If you do not paint your case, we have found that moving the decals into position on a bare aluminum chassis is more difficult, due to the brushed surface, so we advise pre-coating the chassis with a light coating of the Krylon clear before applying the decals.

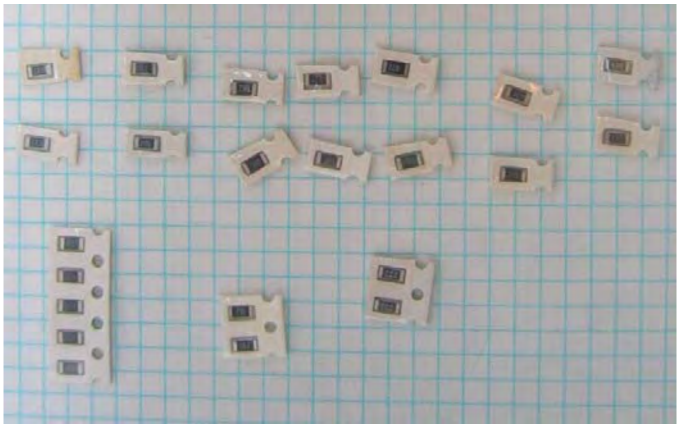
The decals are applied the same as model decals. Cut around each group of text you wish to apply. It doesn't have to be perfect as the background film is transparent. Apply the decals before you mount anything to the chassis. Use the above picture to get the correct spacing around the holes, as it is very easy to do a great decal installation and have a portion covered up with a knob.

Trim around the decal. After trimming, place the decal in a bowl of lukewarm water, with a small drop of dish soap to reduce the surface tension, for 10-15 seconds. Using tweezers, handle carefully to avoid tearing. Start to slide the decal off to the side of the backing paper, and place the unsupported edge of the decal close to the final location. Hold the edge of the decal against the panel, with your finger, and slide the paper out from under the decal. You can slide the decal around to the right position, as it will float slightly on the film of water. Use a knife point or something sharp to do this. When in position, hold the edge of the decal with your finger and gently squeegee excess water out from under the decal with a tissue or paper towel. Work from the center, to both sides. Remove any bubbles by blotting or wiping gently to the sides. Do this for each decal, and take your time. Allow to set overnight, or speed drying by placing near a fan for a few of hours. When dry, spray two **light** coats of matte finish, Krylon, clear to seal and protect the decals, and allow the spray to dry in between coats. All decals come with two complete sets, in case you mess one up.

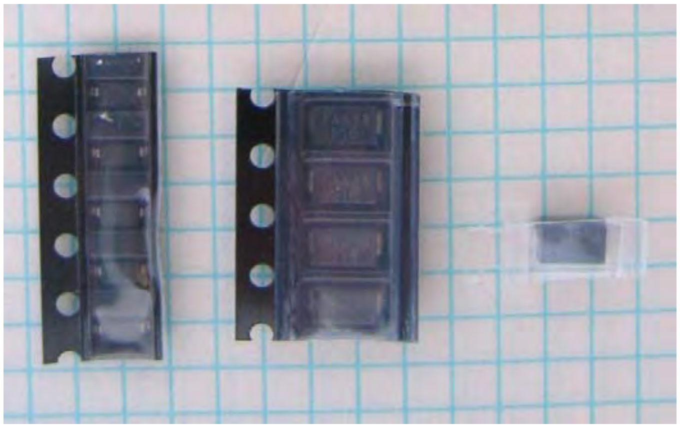
Parts Identification:



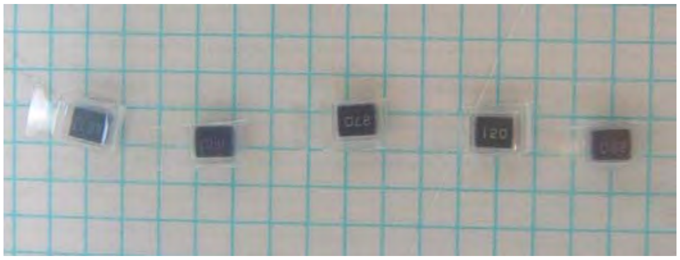
Small Capacitors



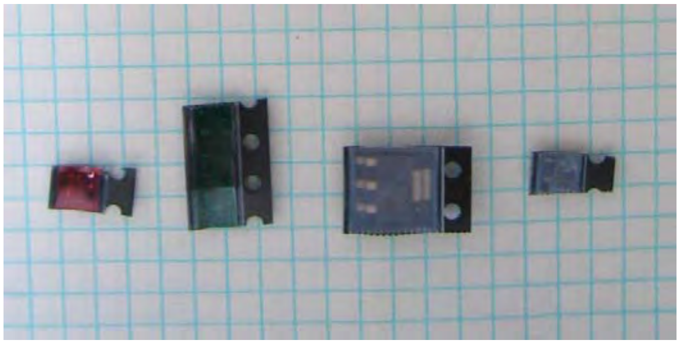
Resistors



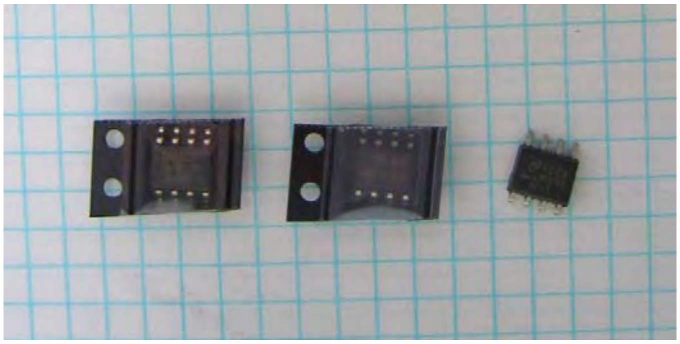
Diodes



Inductors



Transistors

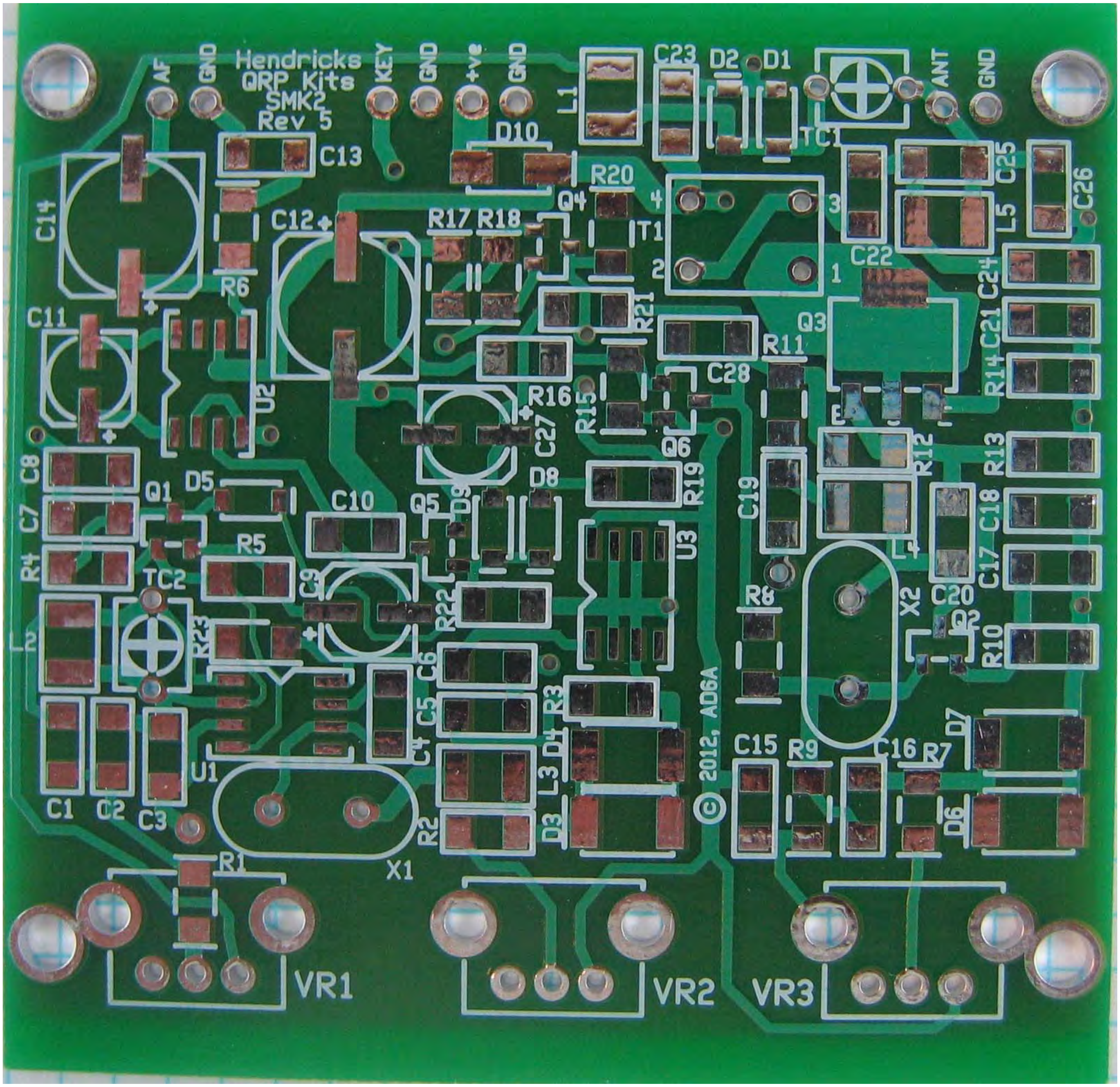


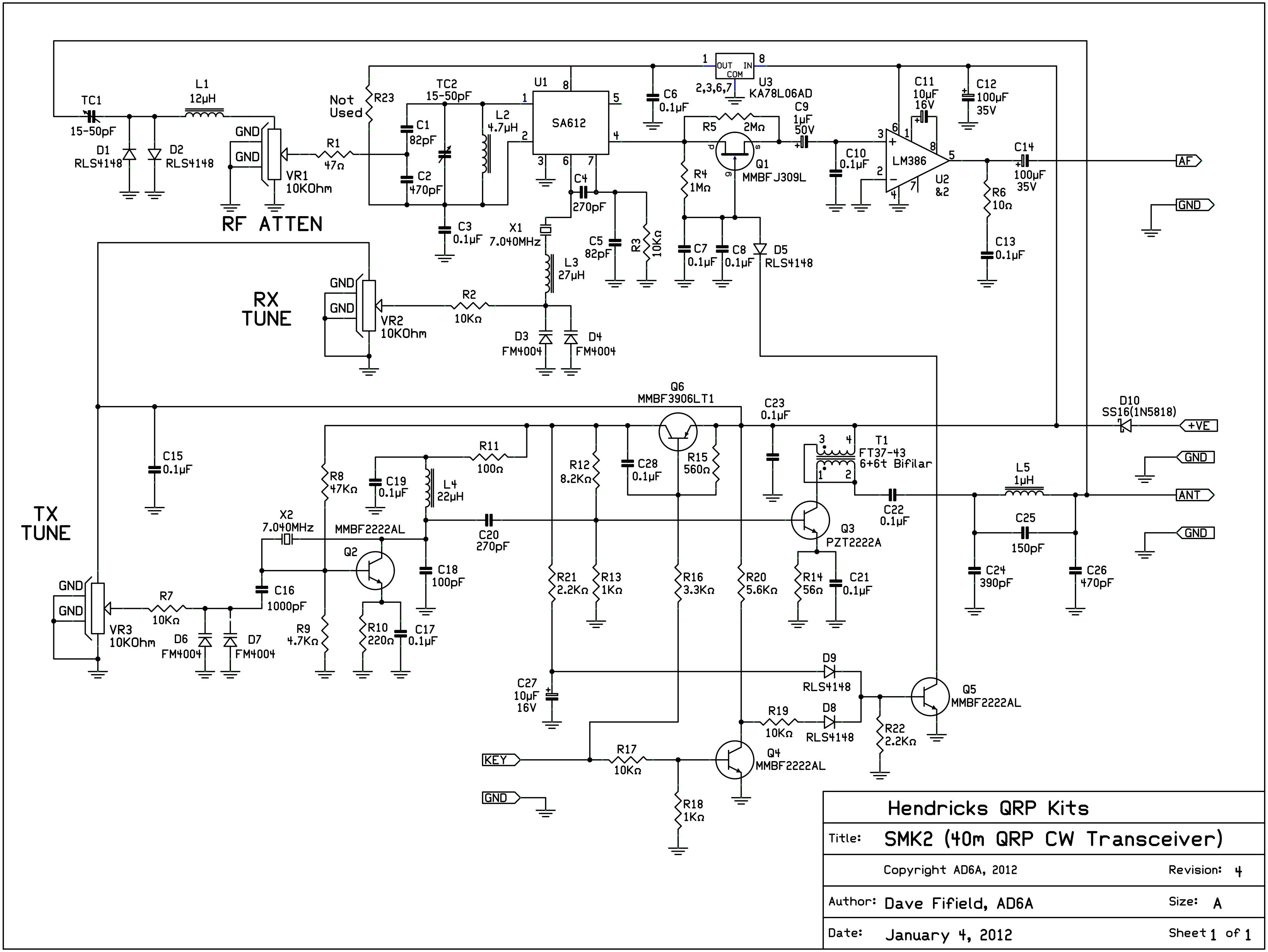
ICs

Electrolytic Capacitor

-	**SMK-2 Parts List**					
Item #	Description	Package	Value	Quantity	Marked	Circuit References
1	Capacitor Ceramic NPO	1206	82pF	3	blue	C1,5,25
2	Capacitor Ceramic NPO	1206	100pF	1	brown	C18
3	Capacitor Ceramic NPO	1206	270pF	2	red	C4,20
4	Capacitor Ceramic NPO	1206	390pF	1	orange	C24
5	Capacitor Ceramic NPO	1206	470pF	3	yellow	C2,26
6	Capacitor Ceramic NPO	1206	1000pF	3	green	C16
7	Capacitor Ceramic X7R	1206	0.1uF	13	black	C3, 6, 7, 8, 10,13,15,17,19, 21,22,23,28
8	Capacitor Aluminum Elec.	B	1uF 50V	1	1 50A or 1 50S	C9
9	Capacitor Aluminum Elec.	B	10uF 16V	2	10 16A or 10 16S	C11,27
10	Capacitor Aluminum Elec.	D	100uF 16V	2	100-35V	C12,14
11	Diode 1A (=1N4004)	DO214	SS16	4	SS16	D3,4,6,7
12	Diode 1A (=1N5818)	DO214	GF1G	1	GF1G	D10
13	Diode Small Signal (=1N4148)	LL-34	RLS4148	5	A2YN or RLS4148	D1,2,5,8,9
14	Inductor	1210	1uH	1	1R0	L5
15	Inductor	1210	4.7uH	1	4R7	L2
16	Inductor	1210	12uH	1	120	L1
17	Inductor	1210	22uH	1	220	L4

item #	Description	Package	Value	Quantity	Marked	Circuit References
18	Inductor	1210	12uH	1	120	L3
19	Transistor NPN (=2N2222A)	SOT-23	MMBF2222AL	3	green	Q2,4,5
20	Transistor PNP (=2N3906)	SOT-23	MMBF3906LT1	1	red	Q6
21	Transistor FET (=J309)	SOT-23	MMBFJ309LT1	1	(clear)	Q1
22	Transistor NPN (=2N2222A)	SOT-223	PZT2222A	1	RN8 P1F or R98 P1F	Q3
23	Resistor 1/16th Watt 5%	1206	10	1	100	R6
24	Resistor 1/16th Watt 5%	1206	47	1	470	R1
25	Resistor 1/16th Watt 5%	1206	56	1	560	R14
26	Resistor 1/16th Watt 5%	1206	100	1	101 or 100R	R11
27	Resistor 1/16th Watt 5%	1206	220	1	221	R10
28	Resistor 1/16th Watt 5%	1206	560	1	561	R15
29	Resistor 1/16th Watt 5%	1206	1K	2	102	R13,18
30	Resistor 1/16th Watt 5%	1206	2.2K	2	222	R21,22
31	Resistor 1/16th Watt 5%	1206	3.3K	1	332	R16
32	Resistor 1/16th Watt 5%	1206	4.7K	1	472	R9
33	Resistor 1/16th Watt 5%	1206	5.6K	1	562	R20
34	Resistor 1/16th Watt 5%	1206	8.2K	1	822	R12
35	Resistor 1/16th Watt 5%	1206	10K	5	103	R2,3,7,17,19
36	Resistor 1/16th Watt 5%	1206	47K	1	473	R8
37	Resistor 1/16th Watt 5%	1206	1M	1	105	R4
38	Resistor 1/16th Watt 5%	1206	2M	1	205	R5
39	Not used	Not used	Not used	Not used	Not used	R23
40	Trimmer Capacitor (orange)	Thru-hole	15-50pF	2	orange	TC1,TC2
41	Toroid Core (black)	Toroidal	FT37-43	1	blck	T1
42	Nysol coated copper wire (red)	26awg	9" long	1	red	T1
43	Nysol coated copper wire (green)	26awg	9" long	1	green	T1
44	Mixer/Oscillator	SO-8	SA612AD	1	A602A	U1
45	Audio Amplifier	SO-8	LM386M-1	1	LM386M-1	U2
46	Voltage Regulator +6V 100mA	SO-8	L78L06CD	1	78L06	U3
47	Linear Potentiometer	Thru-hole	10K	3	-	VR1,VR2,VR3
48	Crystal Socket	3 Pin SIP		2	-	X1,X2
49	Hookup Wire	#22		2ft.	-	
50	Stereo Jack	3507		2	-	
51	Power Jack	2.1mm	Snap In	1	-	
52	BNC			1	-	
53	Rubber Feet			4	-	
54	Case			1	-	
55	Printed Circuit Board	-	SMK-2 PCB	1	SMK-2 PCB	
56	Crystals	HC49/U	7.030 MHz	2	7.030 MHz	X1,X2
57	Crystals	HC49/U	7.040 MHz	2	7.040 MHz	X1,X2





Hendricks QRP Kits

Title: SMK2 (40m QRP CW Transceiver)

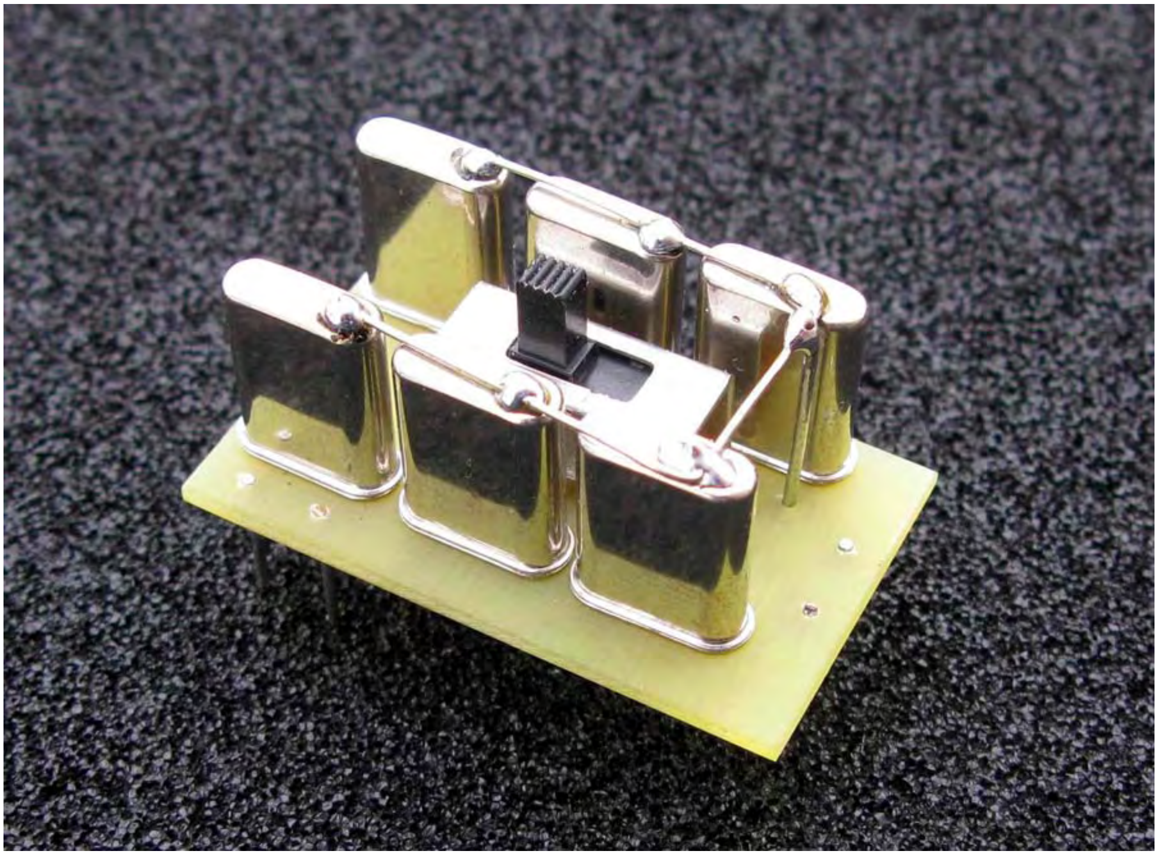
Copyright AD6A, 2012 — Revision: 4

Author: Dave Fifield, AD6A — Size: A

Date: January 4, 2012 — Sheet 1 of 1

Optional Hendricks SMK-2 Switched Crystal Board Assembly

(Optional accessory not included with basic kit)

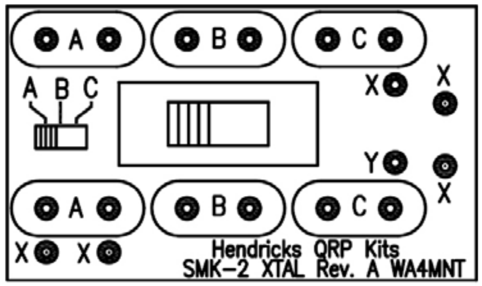


First off, check to see if the parts match the parts list…

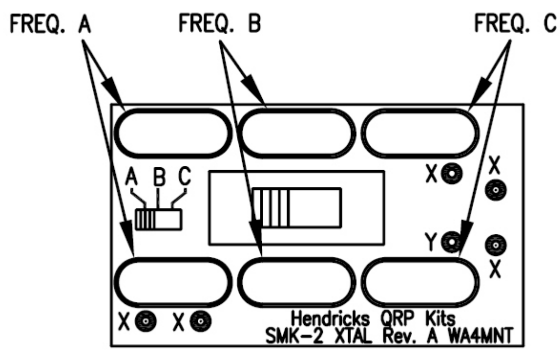
2 – 7122 kHz crystals
1 – DP3T slide switch
1 – 8" - 20AWG tinned wire
1 – PCB

Please read all the instructions before starting. This optional multi-crystal board should be added to your SMK-2 main board only after you have completed assembly and tested the main board. The basic SMK-2 kit comes with two sets of crystals (7030 and 7040 kHz.) The optional switched crystal board comes with a third set of crystals (7122 kHz.) You may use these crystal sets or another set for a frequency of your choice. This board will work with one, two, or three sets of crystals (or a combination of crystals and SIP sockets.)

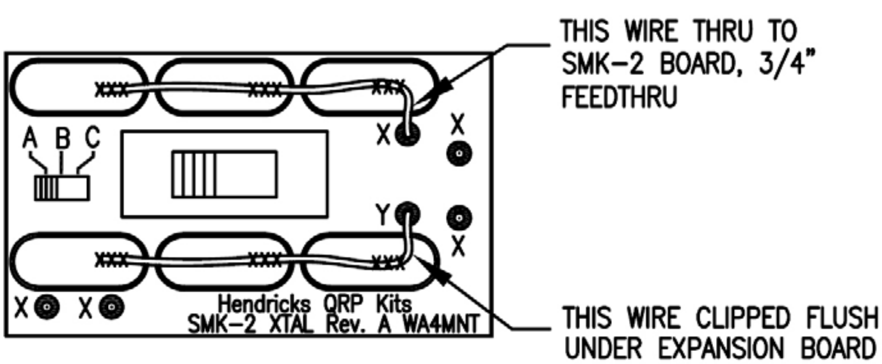
- Install the DP3T switch on the side of the PCB with the silk screening.



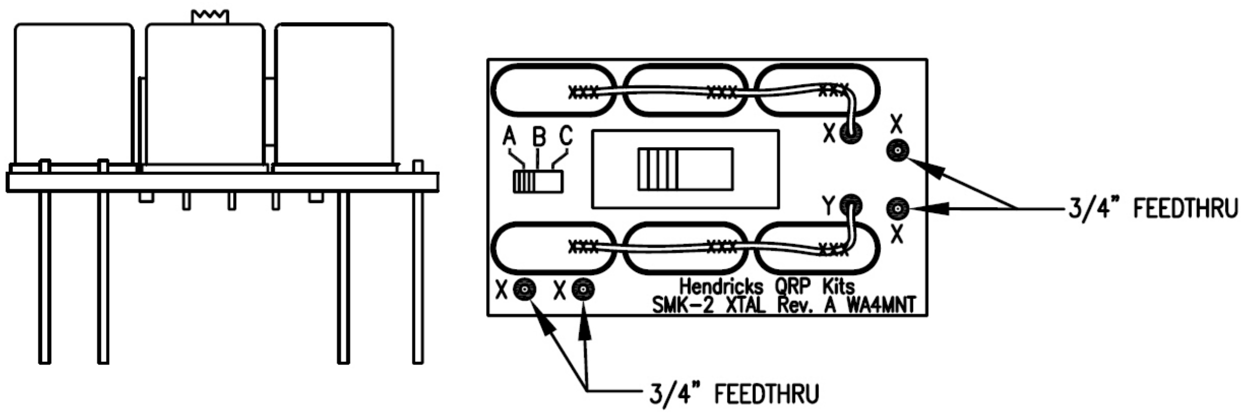
- Decide which frequency you want to be designated as "A", "B", and "C" and solder the crystals on the same side as the switch.



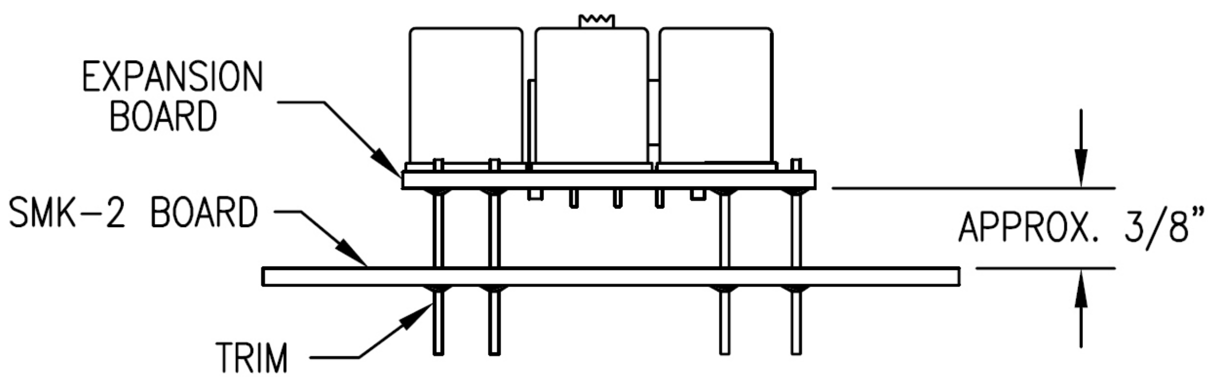
- It is common practice to tie all the crystal cases to ground. Note: You may choose not to do this operation if you plan on changing crystals frequently, or use SIP sockets in one or more of the crystal locations. Do not linger soldering the tinned wire to the crystal cases. The crystals are fairly tolerant, but they can be damaged by high prolonged heat. Cut two 3" pieces of the supplied tinned wire. After soldering the wires to the top of the crystals, the wire passing through the "Y" hole can be trimmed off flush on the far side, but the "X" wire will need to extend approximately 3/4" below the board for connecting to the main SMK-2 board.



- Next you need to cut four pieces of the tinned wire, 3/4" long and solder them to the "X" holes on the backside of the board, as shown below. These leads will connect the expansion board to the X1 and X2 crystal positions of the main board.



- Mounting of the expansion board to the main SMK-2 board is accomplished by aligning the five 3/4" long leads of the expansion board, passing through pads of the existing two crystal positions and ground connection. Space the two boards apart approximately 3/8" so that the expansion board clears C27, and solder the interconnecting leads to the back side of the SMK-2 board, and trim flush.



- Mount the SMK-2 and expansion board assembly into the chassis and complete the I/O connections.

smk2_xtal_assy_030612.pdf

Subject Another Ugly Choke Balun by G4APL

This article has been updated in October 2009 with Paul's experience with half a TA31jnr driven element used as a HF vertical that has been laying around in the garden. (back yard).

Paul g4apl came across an excellent web site URL http://www.hamuniverse.com/balun.html run by Don Butley N4UJW early in 2007.

Don has brought together some excellent examples on how to construct and build a Choke Balun.

In September 2007, Paul decided to build two or three of them, depending on what material could be found in the shed.

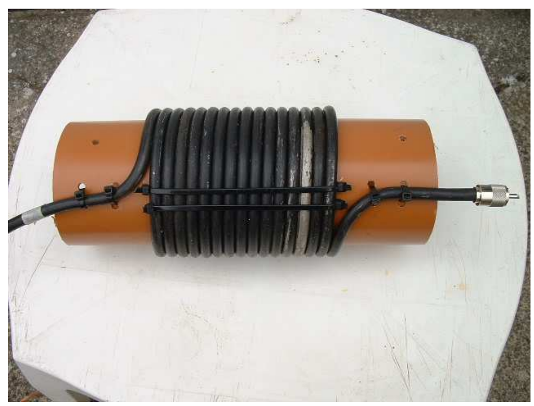
The idea was to add a balun to the HF beam a Mosley Mustang Mark3 3 element 10,15,20 metre trapped yagi. This is fed with co-ax and has the Mosley earth strapped at the feed point. The beam has been adjusted for the low end of the HF (High Frequency) bands.

Paul had used a commercial balun in the 1970's before and burnt this one out. Supposed to be rated to 1 kilowatt pep. (peak envelope power).

Using the information material from Don's web site http://www.hamuniverse.com/balun.html time was to see what was in the shed.

Found a short length of 4 inch drain pipe. Left over from the 90 foot of drain pipe laid underground that carries the RF cables. Also found a 2 inch piece of down pipe.

Materials
HF Beam Balun
12 inches length of 4inch diameter PVC drain pile
cable ties
18 foot of RG58
two suitable cable plugs



G4APL Ugly Choke Balun

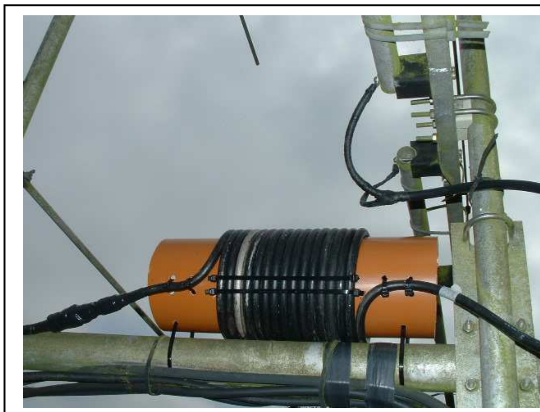
Having got all the required tools out. Took Paul and hour to build the Ugly Choke Balun as pictured below

The HF Balun is attached vertically to the Stub Mast about the Mosley Mastang Mark3 beam

Paul was very surprised with the results. Testing the aerial and Balun with 250 Watts the standing wave was surprisingly good.
Never seen this beam produce these results before

14.005MHz to 14.150MHz	1.1:1
14.200MHz	1.2:1
14.250MHz	1.4:1
14.300MHz	1.9:1
21.005MHz to 21.300	1.1:1
21.400MHz	1.2:1
28.005MHz – 28:400MHz	1.1:1
28.500MHz	1.2:1

Now to do some dxing and see how the aerial performs.



G4APL Ugly Coke Balun mounted on the tilted over Tower Stub Mast

Pictured below is another G4APL Ugly Choke Balun inline with the GB7CIP Pactor Trapped HF Ground Plane.

G4APL Ugly Balun and feeder protected by hose pipe to prevent Foxes cutting the cable

5 band Trapped HF vertical with the G4APL Balun on the fence.

In October 2009 after experimenting during the summer with half of a Mosley TA31jnr trapped dipole.

That was used in the 1970's as part of a TA33jnr HF beam (Which has been replaced with a Mosley Mustang Mark2 and Mark3 3 element beam since then) as a 10, 15, 20 metre trapped vertical . This is used with the GB7CIP HF PACTOR HF mail forwarding system.

There are no radials used with this. Though some tests were carried out and no noticeable improvement was noticed Not enough room to lay a ground mat of radials.

Half of the TA31 driven element (TA31jnr) was mounted to a section of aluminium attached to 2 feet of aluminium pole driven in to the ground using an SDS hammer drill so as not to damage the pole.

The element was attached to the insulating blocks with screws. Cable ties are used to add additional strength and reduce the strain on the element feed point due to movement caused by strong winds.

A spare feeder about 16 Metres long was removed from the Tower to it's base. 15 Metres of Aqua 1 ½ Inches (40mm) diameter flexible water pipe was purchase from a local garden centre.

This was laid under the lawn to the base of the vertical. The cable was pulled through using 16 metres of drain rods, which took 20 minutes from taking the rods out of the bag and replacing them.

G4APL TA31jnr as a trapped HF vertical

G4APL TA31Jnr HF vertical mounting and feed arrangements

Paul was disappointed to find that having removed about 70 feet (21 Metres) of cable attached to the tower feeder. That the SWR was reading over 3:1 on 15 and 20 Metres.

Time to build another G4APL Ulgly Choke Bulan.

G4APL TS-480SAT Tuned to 21.110.40MHz SWR showing two bars < 1.5:1

G4APL TS-480SAT Tuned to 14.108.90MHz SWR showing two bars < 1.5:1

G4APL Feeders at the base of the tower

Bingo a good match, as seen in the photographs of the Kenwood TS480SAT with a 100 Watts of FSK on 20 and 15 Metres display and SWR less that 1.5:1 instead of over 3:1

Hope the above of use to you and allow you to experiment.

73 Paul G4APL

10

Design Issues in Radio Frequency Energy Harvesting System

Chomora Mikeka and Hiroyuki Arai
Yokohama National University
Japan

1. Introduction

Emerging self powered systems challenge and dictate the direction of research in energy harvesting (EH). State of the art in energy harvesting is being applied in various fields using different single energy sources or a combination of two or more sources. In certain applications like smart packaging, radio frequency (RF) is the preferred method to power the electronics while for smart building applications, the main type of energy source used is solar, with vibration & thermal being used increasingly. The main differences in these power sources is the power density; for example RF (0.01 ~ 0.1 μW/cm^2), Vibration (4 ~ 100 μW/cm^2), Photovoltaic (10 μW/cm^2 ~ 10mW/cm^2) and Thermal (20 μW/cm^2 ~ 10mW/cm^2). Obviously RF energy though principally abundant, is the most limited source on account of the incident power density metric, except when near the base stations. Therefore, in general, RF harvesting circuits must be designed to operate at the most optimal efficiencies.

This Chapter focuses on RF energy harvesting (EH) and discusses the techniques to optimize the conversion efficiency of the RF energy harvesting circuit under stringent conditions like arbitrary polarization, ultra low power (micro or nanopower) incidences and varying incident power densities. Harvested power management and application scenarios are also presented in this Chapter. Most of the design examples described are taken from the authors' recent publications.

The Chapter is organised as follows. Section 2.1 is the introduction on RF energy sources. Section 2.2 presents the antenna design for RF EH in the cellular band as well as DTV band. The key issue in RF energy harvesting is the RF-to-DC conversion efficiency and is discussed in Section 2.3, whereas Section 2.4 and 2.5 present the design of DTV and cellular energy harvesting rectifiers, respectively. The management of micropower levels of harvested energy is explained in Section 2.6. Performance analysis of the complete RF EH system is presented in Section 3.0. Finally, conclusions are drawn in Section 4.0.

1.1 RF energy sources

These include FM radio, Analogue TV (ATV), Digital TV (DTV), Cellular and Wi-Fi. We will present a survey of the measured E-field intensity (V/m) for some of these RF sources as shown in Table 1, [1]-[2]. Additionally, measured RF spectrums for DTV and Cellular signals are presented as shown in Fig. 1 to show on the potential for energy-harvesting in

these frequency bands. In general, many published papers on RF-to-DC conversion, have presented circuits capable of converting input or incident power as low as -20dBm. This means that, if an RF survey or scan finds signals in space, with power spectrum levels around -20dBm, then, it is potentially viable to harvest such signal power. In Fig. 1 (left side), the spectrum level is well above -20dBm and hence, a higher potential for energy harvesting. In Fig. 1 (right side), while the spectrum level is below -20dBm, what we observe is that the level increases with decrease in the distance toward the base station (BTS). Using free space propagation equation with this data, it was calculated that at a distance 1.4 m from the BTS, the spectrum level could measure 0dBm. An example calculation and plot for the estimated received power level, assuming 0dBi transmitter (BTS) and receiver antenna gains and free space propagation loss (FSPL) for FM and DTV is presented in Section 2.1.1. For the example estimation in Section 2.1.1, we select FM and DTV because they measured with a higher level than cellular and Wi-Fi for example.

Source	V/m	dBm	Reference	
FM radio	0.15~3		Asami et al.	
Analogue TV	0.3~2			
Digital TV	0.2~2.4	-40~0.0	Asami et al.	Arai et al.
Cellular		-65~0.0	Mikeka and Arai	
Wi-Fi		≅ -30		

Table 1. RF energy sources, measured data.

In Table 1, FM radio has the highest E-field intensity implying the highest potential for energy harvesting. However, due to the requirements for a large antenna size and the challenges for simulations and measurements at the FM frequency i.e. 100 MHz or less (See Section 2.2.3, example FM antenna at 80 MHz), this Chapter will focus on DTV (470~770 MHz band) and Cellular (2100 MHz band) energy harvesting.

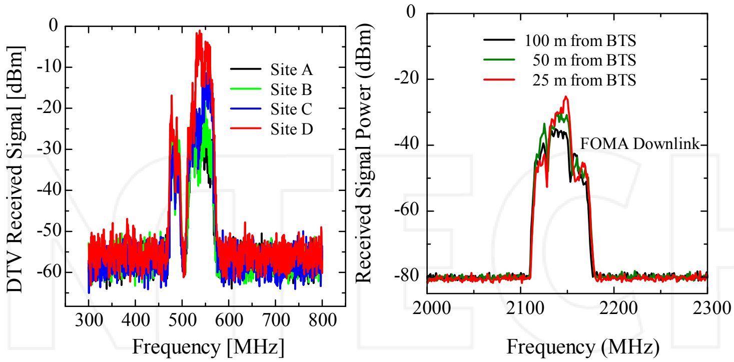


Fig. 1. DTV signal spectrum measured in Tokyo City (left side graph) and Cellular signal spectrum measured in Yokohama City (right side graph).

The received DTV signal power is high and also wide band, presenting high potential for increased energy harvesting unlike in cellular signals. We demonstrated in [2] that the total RF-to-DC converted power is roughly the integral over the DTV band (1), and is significantly larger than in the case of narrow band cellular energy harvesting.

$$P_{DC(DTV)} = \alpha \int_{470}^{770} \delta P_{DC}\left(f\right) df \ , \tag{1}$$

where α is the attenuation factor on the rectifying antenna's RF-to-DC conversion efficiency due to multiple incident signal excitation. δP_{DC} is the small converted DC power from each of the single DTV signals in the 470 MHz to 770 MHz band.

In detail, we derive (1) from fundamentals as follows.

The incident power density on the rectifying antenna (rectenna), $S\left(\theta,\phi,f,t\right)$, is a function of incident angles, and can vary over the DTV spectrum and in time. The effective area of the antenna, $A_{eff}\left(\theta,\phi,f\right)$, will be different at different frequencies, for different incident polarizations and incidence angles. The average RF power over a range of frequencies at any instant in time is given by:

$$P_{RF}\left(t\right) = \frac{1}{f_{high} - f_{low}} \int_{f_{low}}^{f_{high}} \int_{0}^{4\pi} S\left(\theta,\phi,f,t\right) A_{eff\left(\theta,\phi,f\right)} d\Omega df \tag{2}$$

The DC power for a single frequency (f_i) input RF power, is given by

$$P_{DC}\left(f_i\right) = P_{RF}\left(f_{i,}t\right).\eta\left(P_{RF}\left(f_i,t\right),\rho,Z_{DC}\right), \tag{3}$$

where η is the conversion efficiency, and depends on the impedance match $\rho\left(P_{RF},f\right)$ between the antenna and the rectifier circuit, as well as the DC load impedance. The reflection coefficient in turn is a nonlinear function of power and frequency.

The estimated conversion efficiency is calculated by P_{RF}/P_{DC} . This process should be done at each frequency in the range of interest. However, DC powers obtained in that way cannot be simply added in order to find multi-frequency efficiency, since the process is nonlinear. Thus, if simultaneous multi-frequency or broadband operation like in DTV band is required, the above characterization needs to be performed with the actual incident power levels and spectral power density. In this Chapter, we shall demonstrate DTV spectrum power harvest, given a rectenna than has been characterised in house at each single frequency in the DTV band.

1.1.1 An example calculation and plot for the estimated received power level

In this example we consider Tokyo's DTV and FM base stations (BS) as the RF sources. Both DTV and FM BS transmitter power (P_t) equals 10 kW (70dBm). The antenna gains are assumed 0dBi in both cases but also at the points of reception for easiness of calculation but with implications as follows. Assuming 0dBi antenna at each reception point, demands that we specify the frequency of the transmitted signal. For this reason we specify DTV signal frequency to be equal to 550 MHz while the FM signal frequency equals 80 MHz (Tokyo FM).

The received power, P_r is calculated using the simplest form of Friis transmission equation given by

$$P_r = P_t + G_t + G_r + FSPL, \tag{4}$$

where P_t = 70dBm, $G_t = G_r$ = 0dBi. G_r is the receiving antenna gain while FSPL is the free-space path loss given by

$$FSPL(dB) = 20\log(d) + 20\log(f) + 32.45, \tag{5}$$

where $\boldsymbol{d}$ is in (km) and $\boldsymbol{f}$ is in (MHz). The plot for the received power as a function of distance from the DTV and FM base stations is shown in Fig. 2.

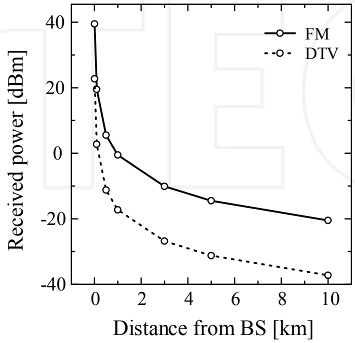


Fig. 2. DTV and FM received signal power level against distance.

With respect to Fig. 2, FM registers higher received power level than DTV at every reception point due to its lower transmit frequency and hence lower free-space path loss. For example at 1 km distance, FM received power level is -0.51dBm while for DTV, the received power is -17.26dBm. The important thing however, is that the received power level is frequency independent. It means that P_t is the transmitter power and the received power level at the position of distance $\boldsymbol{d}$ is $\frac{P_t}{4\pi d^2}$. However, if we assume 0dBi antenna at each reception point as in the above example, the power level is different because the antenna size of 0dBi is frequency dependent. As a result, high transmit power level is favorable for RF energy harvesting. Also near the base station is favorable.

1.2 Antenna design for the proposed RF energy harvesting (EH) system

It is well known that RF EH system requires the use of antenna as an efficient RF signal power receiving circuit, connected to an efficient rectifier for RF-to-DC power conversion. Depending on whether we want to harvest from cellular or DTV signals, the antenna design requirements are different. We will discuss the specific designs in the following sub sections.

1.2.1 Cellular energy harvesting antenna design

We propose a circular microstrip patch antenna (CMPA) for easy integration with the proposed rectifier (Section 2.5.1). However, the use of circular microstrip patch antennas (CMPA) is often challenged by the need for impedance matching, circular polarization (CP) and higher order harmonic suppression.

To address the above concerns, we create notches on the circular microstrip patch antenna. In our approach, we use only two, thin, fully parameterized triangular notches to achieve higher order harmonic suppression, impedance matching and circular polarization, all at once. This is the novelty in our proposed antenna. Our proposed CMPA is shown in Fig. 3. We study the behaviour of CMPA surface current vectors when notches (triangles ABC) are created on the structure at $\alpha = 45^0$ and $\alpha = 225^0$.

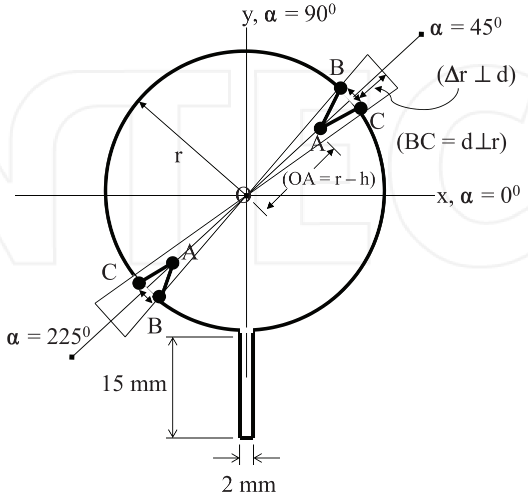


Fig. 3. Cellular energy harvesting antenna structure.

Notch parameters ***d*** and ***h*** in Fig. 3 were investigated by calculation using CST microwave Studio.

Without notches, the CMPA's input is not matched at f_c= 2.15 GHz as shown in Fig. 4 (left side). However, with notches, matching is achieved. The parameter combination ***d*** = 7 and ***h*** = 6 offers a matched and widest band input response and hence we adopt it for cellular energy harvesting applications.

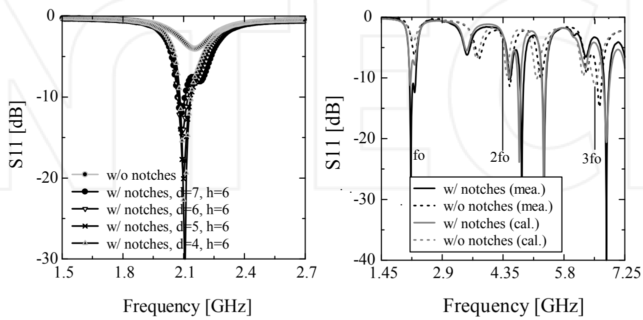


Fig. 4. *Left side:* ***d*** and ***h*** parameter investigation. *Right side:* Comparison between (cal.) and (mea.) S_{11} at f_0 = 2.175 GHz, $2f_0$ = 4.35 GHz and $3f_0$ = 6.53 GHz. The adopted notch parameters are ***d***=7 mm while ***h***= 6 mm.

The comparison between calculated and measured S_{11} is shown in Fig. 4 (right side). The 2nd and 3rd harmonics are suppressed as required by design. The comparison between calculated and measured radiation patterns is shown in Fig. 5, where $E_\vartheta \cong E_\varphi$ due to the 45^0 tilted surface current vector. Ordinarily, without notches, the surface current vector is parallel to the microstrip feeder axis. In conclusion, our proposed CMPA is sufficiently able to suppress higher order harmonics while simultaneously radiating a circularly polarized (CP) wave. The CP is required to efficiently receive the arbitrary polarization of the incident cellular signals at the rectenna.

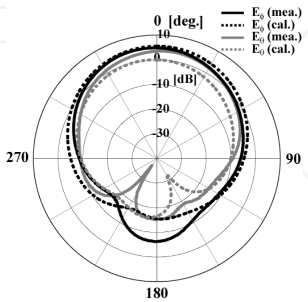


Fig. 5. Cellular energy harvesting antenna pattern at f_c= 2.15 GHz.

1.2.2 DTV energy harvesting antenna design

Unlike in the cellular energy harvesting antenna, the DTV energy harvesting antenna must be wideband (covering 470 MHz to 770 MHz), horizontally polarized and omni-directional.

The proposed antenna is typically a square patch (57 mm x 76 mm) with a partial ground plane (9 mm x 100 mm). The patch is indirectly fed by a strip line (9 mm x 3 mm). The proposed antenna geometry is shown in Fig. 6. The partial ground plane is used to achieve omni-directivity and a certain level of wide bandwidth. To tune the impedance of this antenna as well as to adjust the bandwidth within the target band, a "throttle" with stepped or graded structures is used between the microstrip feed line and the square patch, as shown in Fig. 6 (left side).

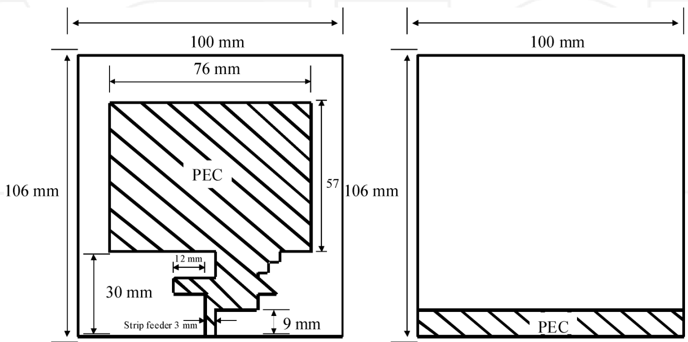


Fig. 6. Proposed DTV antenna geometry. *Left side:* Front view. *Right side:* Back view. The antenna is printed on FR4 substrate; t = 1.6 mm, ε_r = 4.4.

The input response for the proposed antenna is shown in Fig. 7 (left side). The omni directivity is confirmed by measurement at 500 MHz, 503 MHz, and 570 MHz as shown in Fig. 7 (right side). The radiation patterns shown in Fig. 7 are for the xz plane, which happens to be the vertical polarization for the antenna. DTV signals are horizontally polarized and therefore, when using this antenna, the orientation must be in such a way as to efficiently receive the DTV signal. Simply a 90 degree rotation of the antenna along the z axis achieves this requirement.

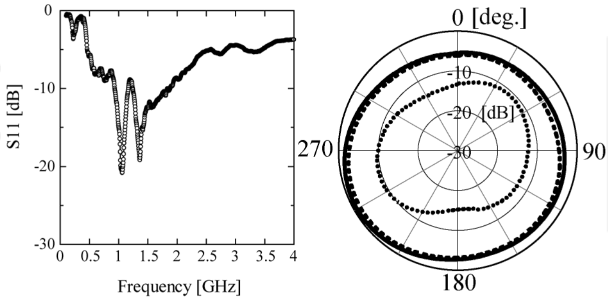


Fig. 7. Proposed DTV antenna performance. *Left side:* The antenna's measured input performance. *Right side:* The omni directivity in the vertical plane is confirmed at 500 MHz, 503 MHz, and 570 MHz. The outermost, black solid and dotted line patterns represent 503 MHz and 500 MHz directivity, respectively. The innermost dotted line pattern is the directivity at 570 MHz.

1.2.3 Example design for an 80 MHz FM half-wave dipole antenna

A half-wave dipole is the simplest practical antenna designed for picking up electromagnetic radiation signals, see Fig. 8 (courtesy of Highfields Amateur Radio Club). Calculating the optimal antenna length to pick up a certain frequency signal is fairly straightforward because antenna physics demand that the total length of wire used in the antenna be equal to one wavelength of the type of electromagnetic radiation it will be picking up. This means that the total length of the antenna should be equal to half the desired wavelength. By converting the 80 MHz frequency into a wavelength, you can thus obtain your antenna length as 1.875m by using the magic equation, $\lambda = \frac{c}{f}$. However, the actual length is typically about 95% of a half wavelength in free space, hence a half-wave dipole for this frequency should be 1.788m long, which would make each leg of the dipole 0.894m in length.

1.3 RF-to-DC conversion efficiency improvement techniques

A Schottky diode circuit connected to an antenna is used for RF-to-DC power conversion. To convert more of the antenna surface incident RF power to DC power, high RF-to-DC conversion efficiency is required of the rectifying circuit. Many authors have shown that the efficiency depends on several factors like Schottky diode type, harmonics suppression capability, load resistance selection, and the capability to handle arbitrary polarized incident waves. What is missing in most of these published works is the efficiency optimization for

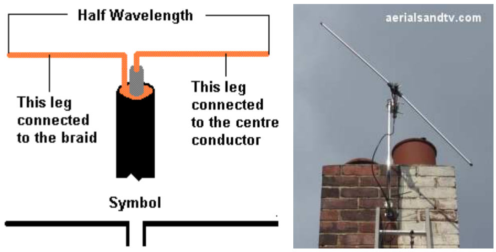


Fig. 8. Half-wave dipole. *Left side:* Antenna structure. *Right side:* Typical deployment.

ultra low power incident waves and the explanation of the physical phenomena behind most of the recommended efficiency optimization approaches.

This Chapter will show for example that a Schottky diode that delivers the highest efficiency at 0dBm incidence may not necessarily deliver the highest efficiency at lower power incidence e.g. –20dBm. We will therefore classify which diodes perform better at given power incidences; of course, this will also be compared to the diode manufacturers' application notes. Simulations in Agilent's ADS using SPICE and equivalent circuit models will compare the performance of few selected Schottky diodes namely; HSMS-2820, HSMS-2850, HSMS-2860, HSC-276A, and SMS7630. Moreover, the effect of the Schottky diode's junction capacitance (C_j) and junction bias resistance (R_j) on the conversion efficiency will be shown from which, special techniques for Schottky diode harmonic suppression and rectifying circuit loading for maximum efficiency point tracking will be presented.

1.3.1 The schottky diode

The classical *pn* junction diode commonly used at low frequencies has a relatively large junction capacitance that makes it unsuitable for high frequency application [3]. The Schottky barrier diode, however, relies on a semiconductor-metal junction that results in a much lower junction capacitance. This makes Schottky diodes suitable for higher frequency conversion applications like rectification (RF-to-DC conversion) [3]. We will demonstrate the effects of junction capacitance and resistance in the following sub section.

1.3.2 The effect of Schottky diode's C_j and R_j on the conversion efficiency

We have studied Schottky diode's C_j and R_j and published our results in [4]. In this work, we designed a rectifying antenna tuned for use at 2 GHz. The circuit proposed in [4] is a voltage doubler by configuration, but we replaced the amplitude detection diode (series diode) with its equivalent circuit adapted from [5]. The results of this investigation show that variation of C_j shifts the tuned frequency position and also introduces a mismatch in the resonant frequency, see Fig. 9 (left side graph). Therefore for this circuit at 2 GHz, we recommend using a Schottky diode having C_j = 0.2pF. In general, a smaller value of C_j is desirable at higher frequencies. Similarly, for R_j investigation, a smaller value is desirable for better matching at 2 GHz for example. If the R_j is increased towards 10kΩ, there is a mismatch in the resonant frequency but no shift in the frequency, see Fig. 9 (right side graph). Another approach to the study of Schottky diodes for higher frequency and efficiency rectenna design is presented in [6].

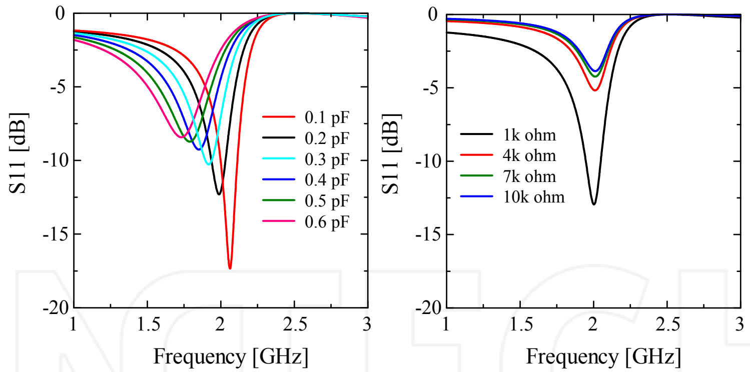


Fig. 9. Schottky diode's C_j effect (Left) and R_j effect (Right) on 2 GHz rectenna's input response.

1.4 Rectifying circuit for DTV energy harvesting

In the design of a DTV energy harvesting circuit, several basic design considerations must be paid attention to. First is the antenna; it must be wideband (covering 470 MHz to 770 MHz), horizontally polarized and omni-directional. Secondly is the rectifier; it must also be wideband, and optimized for RF-to-DC conversion for incident signal power at least -40dBm. Until recently, very few authors have published on DTV energy harvesting circuit. For the few publications, the antenna could not meet all those three requirements and a discussion on the performance of the harvesting circuit for ultra low power incidences has been neglected. In this Chapter we will present such a rectenna with conversion efficiencies above 0.4% at -40dBm, above 18.2% at -20dBm and over 50% at -5dBm signal power incidence. We will closely compare simulated and measured performance of the rectenna and discuss any observed disparities.

Agilent's ADS will be used to simulate the nonlinear behaviour of the rectifying circuit based on harmonic balance tuning methods. To simulate the multiple incident waves, a multi-tone excitation in the DTV band will be invoked. The wideband input characteristic will be achieved by the input matching inductors and capacitors.

The generic version of our proposed DTV energy harvesting circuit is shown below in Fig. 10. The implementation, however, is in two phases or scenarios as follows. First, we investigate the class called "ultra low power" DTV band rectenna. Secondly, we introduce the "medium power" DTV band rectenna.

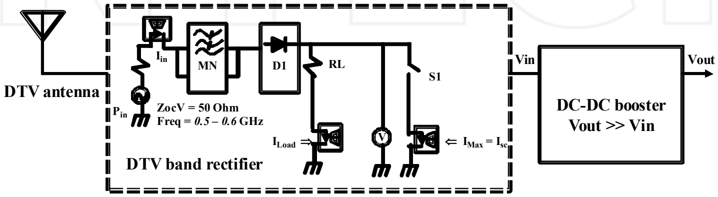


Fig. 10. Generic version of our proposed DTV energy harvesting circuit.

1.4.1 Ultra low power DTV rectenna

We define an ultra low power rectenna as one impinged by RF power incidence in the range between – 40dBm and -15dBm. Below in Fig. 11 is the circuit we designed; optimized for -20dBm input. The matching network is complex so as to achieve a wide band input characteristic. The fabricated circuit was well matched for the frequency range between 470 MHz and 600 MHz. More details about the circuit design can be found in [7].

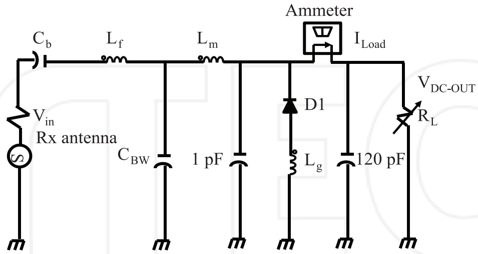


Fig. 11. Ultra low power DTV band rectenna circuit. SMS7630 Schottky diode by SKYWORKS offered the best performance.

The RF-to-DC conversion efficiency for this circuit is shown in Fig. 12 where at input power equal to -40dBm, efficiency is at least 0.4% and rectified voltage equals 1mV; at -20dBm, we have at least 18.2% by measurement and a rectified voltage of 61.7mV. The level of rectified voltage is too low and disqualifies this circuit for purposes of charging capacitors or batteries to accumulate such micropower over time. Instead, boosting the low voltage to usable levels is the option available and we shall discuss this at a later stage, (in Section 2.6).

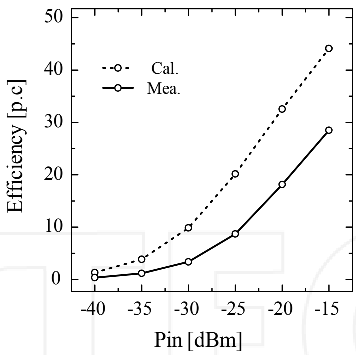


Fig. 12. Ultra low power DTV band rectenna efficiency.

1.4.2 Medium power DTV rectenna

We define a medium power rectenna as one impinged by RF power incidence in the range between – 5dBm and 0dBm. Below in Fig. 13 is the circuit we designed, optimized for -5dBm input. The matching network is simpler than as shown in section 2.4.1 since we require a narrow band around 550 MHz, with received peak power spectrum levels at least -5dBm. The circuit in Fig. 13 is a modification of Greinacher's doubler rectifier. In the circuit, C_b equals 1 pF and is used to block DC current against flowing towards the source. The shunt

capacitance, C_{BW} equals 3300 pF and is used to set the input bandwidth. The grounding inductance, L_g equals 56nH (optimal) and is used to improve the RF-to-DC conversion efficiency by cancelling the Schottky diodes (D_b and D_D) capacitive influence; thereby minimizing the harmonic levels (harmonic suppression). We used HSMS2850 diodes in these circuits for their better performance at this level of incident power.

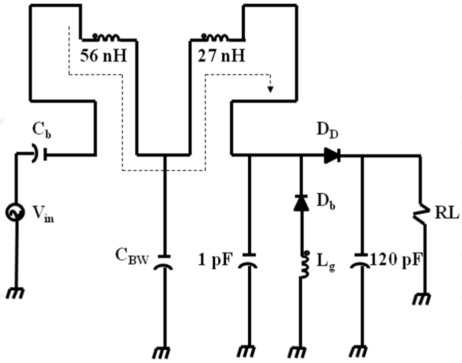


Fig. 13. Medium power DTV rectenna circuit. HSMS 2850 or 2820 from Hewlett-Packard offered the best performance.

The RF-to-DC conversion efficiency for this circuit is shown in Fig. 14 where at input power equal to -5dBm, we achieve at least 50% conversion efficiency by measurement, equivalent to 1.2 V DC rectified at 8.2kΩ optimal load. If we change the load to 47kΩ, over 2 V DC is rectified. This rectenna circuit is ideal for powering small sensors that run on 1.5 V or 2.2 V and draw around 6μA nominal current. If we need to power sensors demanding more power, say at least 2.2 V and 0.3mA to 1.47mA current consumption, we have to accumulate the power in a capacitor over time.

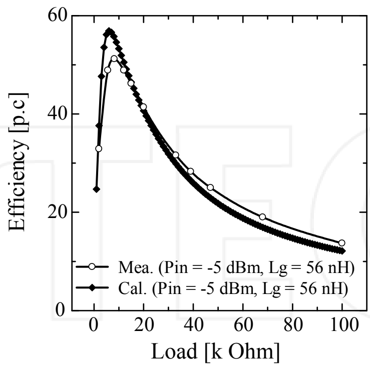


Fig. 14. Medium power DTV band rectenna efficiency.

1.4.3 DTV energy harvesting scenario and application demo

Using the medium power DTV band rectenna, connected to a gold capacitor as an accumulator, energy harvesting was initiated as shown in Fig. 15. Details about the gold

capacitor, which include its charge function, backup time and leakage losses are presented in [8]. For the scenario shown in Fig. 15, the accumulated voltage by measurement i.e. capacitor charge function follows the path;

$$V_{acc} = 0.5388\ln(t) + 1.4681 \tag{6}$$

where V_{acc} is the accumulated voltage in volts and t the time in hours. It takes 4.5 hours to accumulate 2.25 V, given a rectified charging voltage and current of 2.4 V and 51μA, respectively, supplied by the DTV band rectenna instantaneously.

With this rectenna, it was possible to power up many different kinds of sensors. Sensors with ultra low power consumption were powered directly, without need to accumulate the power in a capacitor, as shown in Fig. 16.

Fig. 15. DTV energy harvesting in a park at some line of sight from the base station.

Fig. 16. Directly powering a thermometer mounted on a car park wall (right picture). The maximum instant voltage rectification on record equals 3.7 V (left picture).

1.5 Rectifying circuit for cellular energy harvesting

Unlike in the DTV energy harvesting circuit, for cellular energy harvesting, the antenna must be narrowband (50 MHz bandwidth is acceptable), and circularly polarized even

though cellular signals are vertically polarized. The circular polarization is desired to maximize the RF-to-DC conversion efficiency of the arbitrary polarization incident signals in the multipath environment. Similarly, the rectifier must be narrowband, and optimized for RF-to-DC conversion over a wide range of incident signal power.

Thinking about the potential applications for cellular energy harvesting is useful. Other authors have reported on powering a scientific calculator or a temperature sensor from GSM energy harvesting. In this Chapter we will present a special application for energy harvesting in the vicinity of the W-CDMA cellular base station and analyze the system performance by calculation from experimental data. A cellular energy harvesting circuit optimized for over 50% RF-to-DC conversion efficiency given approximately 0dBm incidence will be presented.

1.5.1 Cellular band rectenna

Below in Fig. 17 is the circuit we designed, optimized for 0dBm input. Simple input matching network is ideal since we require a narrow band response around 2.1 GHz. The optimum value for L_g equals 5.6nH, where L_g is used to improve the RF-to-DC conversion efficiency as earlier discussed. HSMS2850 diode was used.

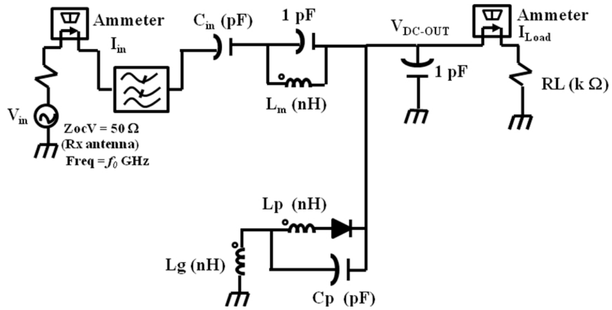


Fig. 17. Shunt rectifier configuration for the cellular band. The matching elements L_m = 3.2nH, while C_{in} =2.5pF. The load resistance is fixed at R_L = 2.1kΩ.

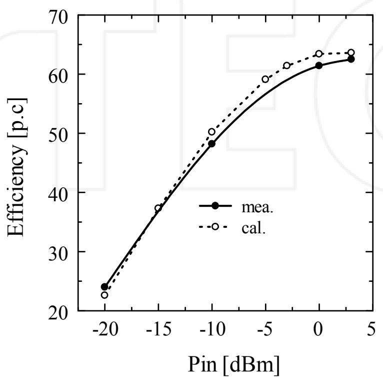


Fig. 18. Conversion efficiency as a function of input power (P_{in}) in the cellular band.

The RF-to-DC conversion efficiency for this circuit is shown in Fig. 18 where at input power equal to 0dBm, we achieve at least 60% conversion efficiency by measurement, given a 2.1kΩ optimal load. This rectenna circuit is ideal for powering small sensors that run on 1.5 V or 2.2 V and 6μA nominal current consumption. If we need to power sensors demanding more power, say at least 2.2 V and 0.3mA to 1.47mA, we have to accumulate the power in a capacitor over time as discussed in section 2.4.3 above.

1.5.2 Cellular energy harvesting application example

Environmental power generation in the neighbourhood of a cellular base station to power a temperature sensor is proposed as shown in Fig. 19 below. Electric field strength measurements in the base station neighbourhood have demonstrated the potential for environmental power generation, and the proposed temperature sensor system is designed based on these values. The rectenna described in Section 2.5.1 is used as the RF-to-DC rectifying circuit with the notched circular microstrip patch antenna (CMPA) proposed in Section 2.2.1. RF-to-DC conversion efficiency equal to 53.8% is obtained by measurement. The temperature sensor made for trial purposes clarifies the capability for temperature data wireless transmission for 20 seconds per every four hours in the base station neighbourhood.

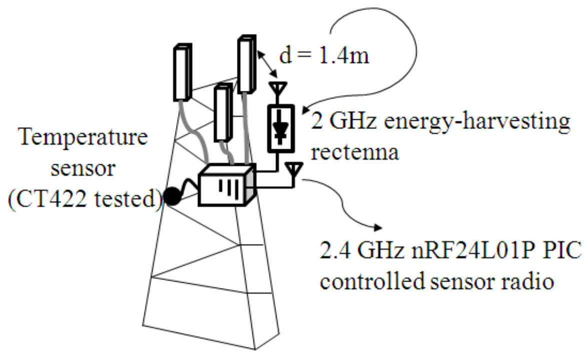


Fig. 19. Application example in the vicinity of the cellular base station.

1.6 Micropower energy harvesting management

A rectifying antenna circuit for -40dBm incident power harvesting generates 1mV at 2kΩ load, given 0.4% efficiency as presented in Section 2.4.1. At -20dBm incidence and at least 18.2% efficiency, 61.7mV is generated given a 2kΩ load [7]. The generated DC power in both of these two cases is in the μW range, hence the micropower definition. To manage such micropower, power accumulation or energy storage is required. Storage devices may either be a gold capacitor, super capacitor, thin film battery or the next generation flexible paper batteries. These storage devices have specific or standard maximum voltage and trickle charging current minimum requirements. Typically, gold capacitors have voltage ratings like 2.7 V, 5.5 V for 100 μA, 10mA or 100mA maximum discharge current. On the other hand, standard ratings for batteries are 1.8 V, 2 V, 3.3 V and 4.1 V. Therefore, to directly charge any of these storage devices from 1mV, or 61.7mV DC is impractical.

Published works have demonstrated the need for a DC-to-DC boost converter placed between the rectifying antenna circuit (rectenna) and the storage device. Recent efforts have demonstrated that a 40mV rectenna output DC voltage could be boosted to 4.1 V to trickle charge some battery. A Coilcraft transformer with turns ratio ($N_s : N_p$) equal to 100 was used in the boost converter circuit. An IC chip leading manufacturer (Linear Technology Corp., LT Journal, 2010) has released a linear DC-to-DC boost regulator IC chip capable of boosting an input DC voltage as low as 20 mV and supplying a number of possible outputs, specifically suited for energy harvesting applications. While this IC is a great milestone, readers and researchers need to understand the techniques to achieve such ICs and also the limitations that apply. In the following sub section, we will describe the methods toward designing a DC-DC boost converter, suitable for micropower RF energy harvesting.

In the design, we will attempt to clarify the parameters that affect the DC-DC conversion efficiency. For this design, Envelope simulation in Agilents's ADS is used. This simulation technique is the most efficient for the integrated rectenna and DC-DC boost converter circuits.

1.6.1 DC-DC boost converter design theory and operation

The DC-DC boost converter design theory and actual implementation are presented in this section. The inequality $V_{in} \ll V_{out}$ defines the boost operation. In this Chapter, our boost converter concept is illustrated in Fig. 20. A small voltage, V_{in} is presented at the input of the boost converter inductive pump which as a result, generates some output voltage, V_{out}. The output voltage is feedback to provide power for the oscillator. The oscillator generates a square wave, F_{OSC} that is used for gate signalling at the N-MOSFET switch.

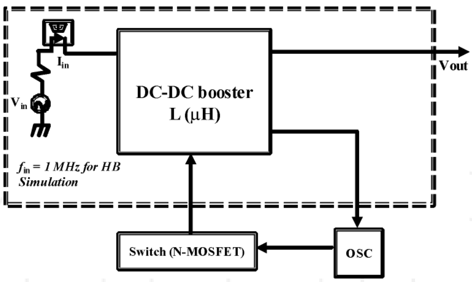


Fig. 20. Boost converter concept.

The drain signal of the N-MOSFET is used as the switch node voltage, V_{sn} at the anode of the diode inside the boost converter circuit block. From the concept presented in Fig. 20, the actual implemented circuit is shown in Fig. 21. The circuit was designed in Agilent's ADS and fabricated for investigation by measurement.

The circuit in Fig. 21 is proposed for investigation. Since a DC-DC boost converter is supposed to connect to the rectenna's output, it therefore, becomes the load to the rectenna circuit. This condition demands that the input impedance of the boost converter circuit emulates the known optimum load of the rectenna circuit. This has the benefit of ensuring

maximum power transfer and hence higher overall conversion efficiency from the rectenna input (RF power) to the boost converter output (DC power). In this investigation, as shown in [7], the optimum load for the rectenna is around 2kΩ. In general, emulation resistance R_{em} is given by

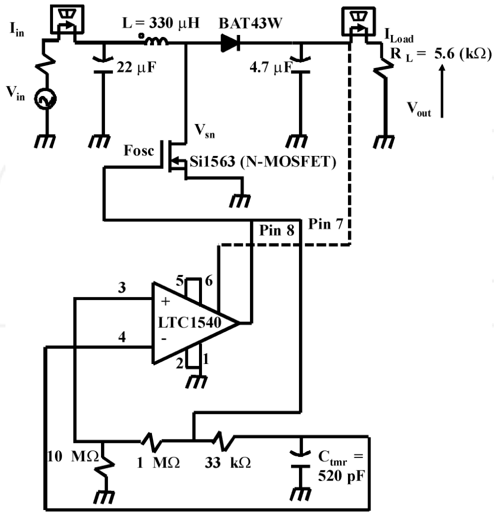


Fig. 21. The proposed boost converter circuit diagram. Designed in Agilent's ADS and fabricated for investigation by measurement.

$$R_{em} = \frac{2LT}{t_1^2 k}\left(\frac{M-1}{M}\right) \tag{7}$$

where $\boldsymbol{L}$ is the inductance equal to 330µH as shown in Fig. 20, $M = \frac{V_{out}}{V_{in}}$, $\boldsymbol{T}$ is the period of F_{OSC}, $\boldsymbol{t_1}$ is the switch"ON" time for the N-MOSFET, and $\boldsymbol{k}$ is a constant that according to [3] is a low frequency pulse duty cycle if the boost converter is run in a pulsed mode and typically, $\boldsymbol{k}$ may assume values like 0.06 or 0.0483. With reference to (7), we select L as the key parameter for higher conversion efficiency while V_{in} = 0.4 V DC is selected as the lowest start up voltage to achieve oscillations and boost operation. Computing the DC-DC boost conversion efficiency against different values of L, we have results as shown in Fig. 22.

From the results above, L = 100µH is the optimum boost inductance that ensures at least 16.5% DC-DC conversion efficiency, given R_L = 5.6kΩ.

Now having selected the optimum boost inductance given some load resistance, the emulation resistance shown in Fig. 23 is evaluated from the ratio of voltage versus current at the boost converter circuit's input.

The results show a constant resistance value against varying inductance. In general, we can say that this boost converter circuit has a constant low input impedance around 82.5Ω. This impedance is too small to match with the optimum rectenna load at 2kΩ. This directly affects the overall RF-to-DC conversion efficiency.

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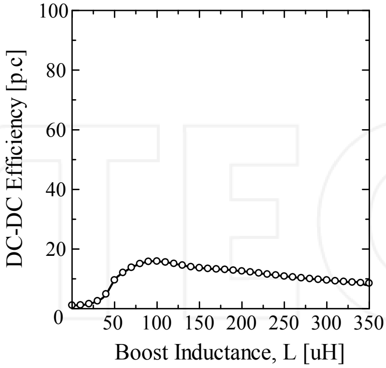

Fig. 22. Boost inductance variation with DC-DC conversion efficiency for a 5.6 kΩ load.

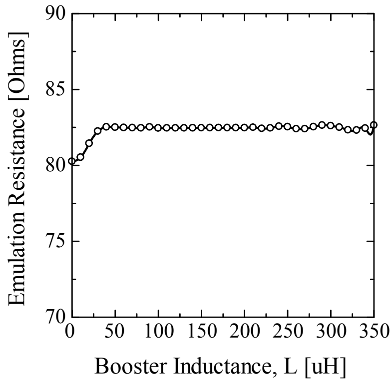

Fig. 23. Boost converter's input impedance: the emulation resistance.

Another factor, which affects the overall conversion efficiency is the power lost in the oscillator circuit. Unlike the circuit proposed in [9], which uses two oscillators; a low frequency (LF) and high frequency (HF) oscillator; in Fig. 21, we have attempted to use a single oscillator based on the LTC1540 comparator, externally biased as an astable multivibrator.

The power loss in this oscillator is the difference in the DC power measured at Pin 7 (supply) to the power measured at pin 8 (output). We term this loss, L_{osc}; converted to heat or sinks through the 10MΩ load. A comparison of the oscillator power loss to the power available at the boost converter output is shown in Fig. 24.

Looking at Fig. 24; we notice that the power loss depends on whether the oscillator output is high or low. The low loss corresponds to the quiescent period where the power lost is

almost negligible. However, during the active state, the lost power (power consumed by the oscillator) nearly approaches the DC power available at the boost converter output. This results in low operational efficiency.

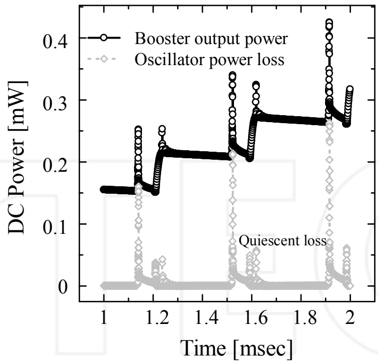

Fig. 24. The power loss in the oscillator.

To confirm whether or not the circuit of Fig. 21 works well, we did some measurements and compared them with the calculated results. Unlike in calculation (simulation), during measurement, L = 330μH was used due to availability. All the other component values remain the same both in calculation and measurement. In Fig. 25 (left side graph) and (right side graph), we see in general that the input voltage is boosted and also that the patterns of F_{osc} and V_{sn} are comparable both by simulation and measurement. To control the duty cycle of the oscillator output (F_{osc}), and the level of ripples in the boost converter output voltage (V_{out}), we change the value of the timing capacitance, C_{tmr} in the circuit of Fig. 21. Simulations in Fig. 25 (left side graph) show that C_{tmr} = 520pF realizes a better performance i.e. nearly constant V_{out} level (very low ripple).

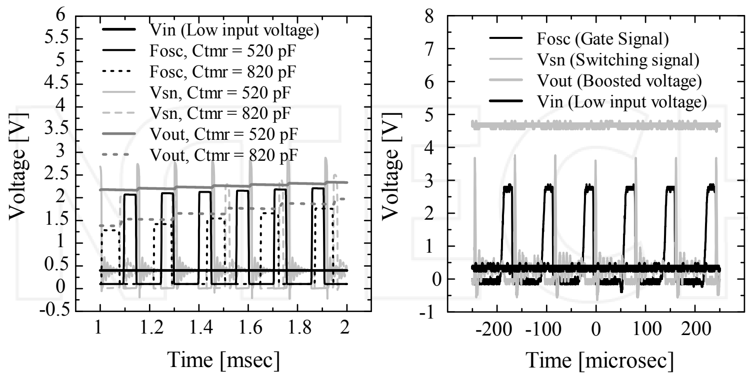

Fig. 25. Voltage characteristics of the developed boost converter circuit. The left side graph represents simulation while the right side graph is for measurements.

Generally, we observe that with this kind of boost converter circuit topology, it is difficult to start up for voltages as low as 61.7mV DC generated by the rectenna at -20dBm power

incidence and at least 18.2% rectenna RF-to-DC conversion efficiency. Self starting is the issue for this topology at very low voltages.

At least 11.3% DC-DC conversion efficiency was recorded by measurement and is comparable to the calculation in Fig. 22. During measurement it was clearly revealed that the boost converter efficiency does depend on the value of **L** and the duty cycle derived from $\mathbf{t_1}$. To efficiently simulate the complete circuit, from the RF input to the DC output, envelope transient simulation (ENV) in Agilent's ADS was used. The (ENV) tool is much more computationally efficient than transient simulation (Tran). This simulation is appropriate for the boost converter circuit's resistor emulation task. Moreover, the boost converter's DC-DC conversion efficiency, and the overall RF-to-DC conversion efficiency can be calculated at once with a single envelope transient simulation.

In summary, though not capable to operate for voltages as low as 61.7mV DC, the proposed boost converter has by simulation and measurement demonstrated the capability to boost voltages as low as 400mV DC, sufficient for battery or capacitor recharging, assuming that the battery or the capacitor has some initial charge or energy enough to provide start-up to the boost converter circuit.

The limitations of our proposed boost converter circuit include; low efficiency, lack of self starting at ultra low input voltages, and unregulated output. To address these limitations, circuit optimization is required. Moreover, alternative approaches which employ a flyback transformer to replace the boost converter inductance must be investigated. A regulator circuit with Low Drop Out (LDO) is necessary to fix the boost converter output voltage commensurate with standard values like 2.2 V DC for example. For further reading, see [7]

2. Performance analysis of the complete RF energy harvesting sensor system

To demonstrate how one may analyze the performance of an RF energy harvesting system including its application, we extend the discussion of Section 2.5.2 to this Section. We propose a transmitter assembled as in Fig. 26 for temperature sensor wireless data transmission.

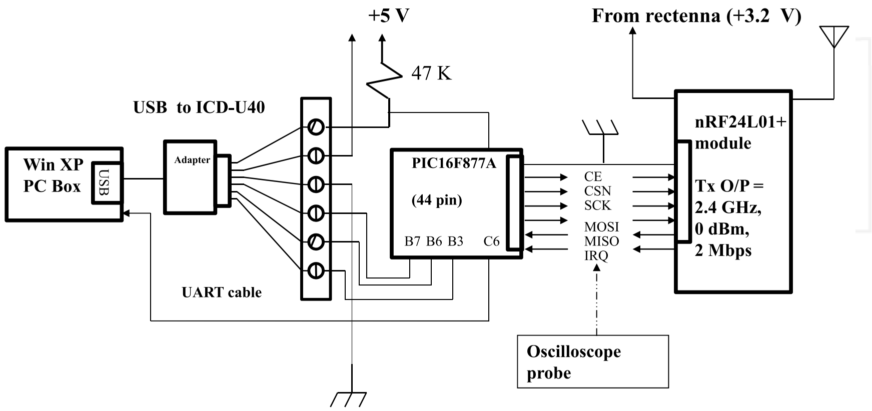

Fig. 26. The assembly and test platform for the proposed battery-free sensor transmitter.

The transmitter consists of one-chip microcomputer (MCU) PIC16F877A and wireless module nRF24L01P for the control, and MCU can be connected with an outside personal computer using ICD-U40 or RS232 cable. The wireless module operates in transmission and reception mode, and controls power supply on-off, transmitting power level, the receiving mode status, and transmission data rate via Serial Peripheral Interface (SPI). Figure 27 shows the operation flow when transmitting.

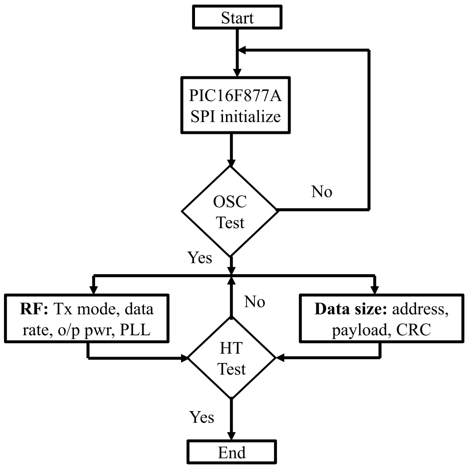

Fig. 27. Operation flow during transmission.

The experimental system composition is shown in Fig. 28 to transmit acquired data by the temperature sensor with WLAN at 2.4 GHz (ISM band). An ISM band sleeve antenna is used for the transmission. Using the cellular band rectenna shown and discussed in Section 2.5.1, at least 3.14 V is stored in the electric double layer capacitor over a period of four hours. To harvest a maximum usable power for the overall system, we charge the capacitor up to 5V. The operation voltage for the wireless module presented in Fig. 26 above is between 1.9V and 3.6V.

The signal was transmitted from the wireless module while a sleeve antenna, same like the one for transmission was used with the spectrum analyzer and the reception experiment was performed. Received signal level equal to -43.4dBm was obtained at a distance 3.5m between transmitter and reception point. The capacitor's stored voltage was used to supply the wireless module in the above-mentioned experiment. Successful transmission was possible for 5.5 minutes after which, the capacitor terminal voltage decreased from 3.16V to 1.47V, and the transmission ended. The sending and receiving distance of data can be estimated to be about 10m when the sensitivity of the receiver is assumed to be -60dBm, given 0dBm maximum transmit power.

Hereafter, the overall system examination is done by environmental power generation using the transmitted electric waves from the cellular phone base station, proposed based on the above-mentioned results. First of all, the power consumption shown in Fig. 29 is based on the fact that 120mW (5V, 24mA) is saved in the electric double layer capacitor by environmental power generation, achieved by calculation as discussed earlier.

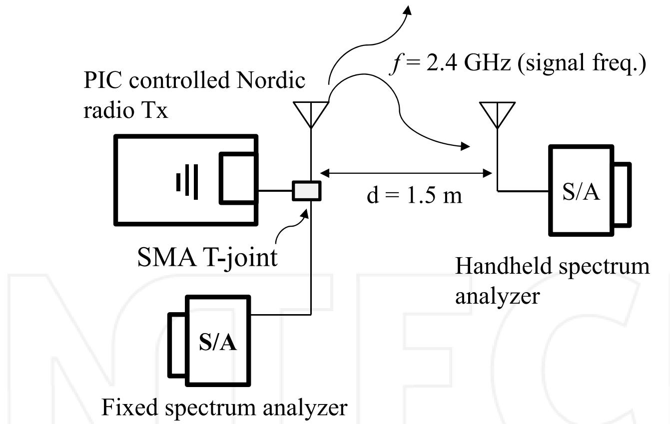

Fig. 28. Indoor measurement setup for received traffic from the sensor radio transmitter.

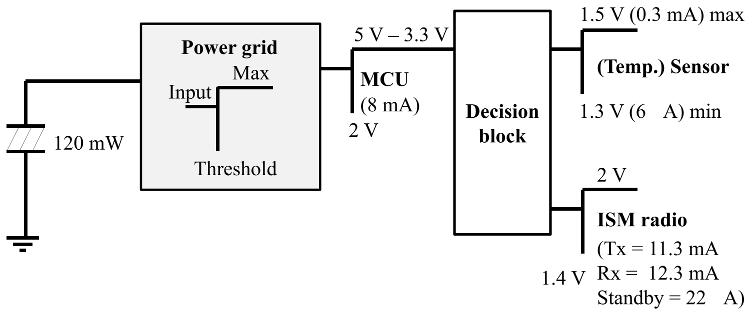

Fig. 29. Power management scheme for the cellular energy-harvesting sensor node.

The sensor data packet is transmitted wirelessly in ShockBurst mode for energy efficient communication. The data packet format includes a pre-amble (1 byte), address (3 bytes), and the payload i.e. temperature data (1 byte). The flag bit is disregarded for easiness, and cyclic redundancy check (CRC) is not used.

The operation of the proposed system is provisionally calculated. When the rectenna is set up in the place where power incidence of 0dBm is obtained in the base station neighbourhood (as depicted in Section 2.5.2), an initially discharged capacitor accumulates up to 3.3V by a rectenna with 53.8% conversion efficiency (presented in Section 2.5.1). At this point, it takes 1.5 minutes to start and to initialize a wireless module, and the voltage of the capacitor decreases to 2V. This trial calculation method depends on the capacitor’s back up time discussed in [8]. After this, when the wireless module is assumed to be in sleep mode, the capacitor is charged by a 0.28mA charging current for four hours whereby the capacitor’s stored voltage increases up to 5V. The power consumption in the sleep mode or standby is 33μW (1.5V, 22μA).

When the wireless module starts, after data transmission and the confirmation signal is sent, the voltage of the capacitor decreases by 0.6V, and consumes the electric power of 7.4mW.

The voltage of the capacitor decreases to 2V when 3.2mW is consumed to the acquisition of the sensor data, and the operation time of MCU is assumed to be one minute to the data storage in the wireless module etc. As for the capacitor voltage, when the wireless module continuously transmits data for 20 seconds, it decreases from 2V to 1.4V and even the following operation saves the electric power. Therefore, a temperature sensing system capable of transmitting wireless data in every four hours becomes feasible by environmental power generation from the cellular phone base station if we consider intermittent operation by sleep mode.

3. Conclusion

This Chapter has given an overview of the present energy harvesting sources, but the focus has stayed on RF energy sources and future directions for research. Design issues in RF energy harvesting have been discussed, which include low conversion efficiency and sometimes low rectified power. Solutions have been suggested by calculation and validated by measurement where possible, while highlighting the limitations of the proposed solutions. Potential applications for both DTV and cellular RF energy harvesting have been proposed and demonstrated with simple examples. A discussion is also presented on the typical performance analysis for the proposed RF energy harvesting system with sensor application.

4. Acknowledgment

The authors would like to thank Prof. Apostolos Georgiadis of Centre Tecnològic de Telecomunicacions de Catalunya (CTTC, Spain) for the collaboration on the design and development of the DC-DC boost converter circuit. Further thanks go to all those readers who will find this Chapter useful in one way or the other.

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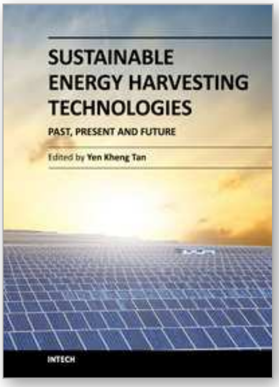

Sustainable Energy Harvesting Technologies - Past, Present and Future

Edited by Dr. Yen Kheng Tan

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In the early 21st century, research and development of sustainable energy harvesting (EH) technologies have started. Since then, many EH technologies have evolved, advanced and even been successfully developed into hardware prototypes for sustaining the operational lifetime of low?power electronic devices like mobile gadgets, smart wireless sensor networks, etc. Energy harvesting is a technology that harvests freely available renewable energy from the ambient environment to recharge or put used energy back into the energy storage devices without the hassle of disrupting or even discontinuing the normal operation of the specific application. With the prior knowledge and experience developed over a decade ago, progress of sustainable EH technologies research is still intact and ongoing. EH technologies are starting to mature and strong synergies are formulating with dedicate application areas. To move forward, now would be a good time to setup a review and brainstorm session to evaluate the past, investigate and think through the present and understand and plan for the future sustainable energy harvesting technologies.

Homebrew Buddipole Variant
By
Paul – AE5JU

History: The Buddipole is a portable dipole using telescoping whips on the ends of center arms, with loading coils between the arms and whips. Originally a homebrew item made from pvc pipe fittings, and rather flimsy. Later they produced a commercial version.

http://www.qsl.net/w3ff/

http://www.buddipole.com/buddipole.html

Just what we need for emergency services, portable, the ability to work various HF bands. So, mine's going to be a little stronger than the pvc homebrew Buddipole. I live in a place you can for sure buy hardware!

01 Bench Grinder Work — Those are 3/8-24 hex joiner nuts I got from HamCQ.

http://www.hamcq.com/whips-quick-disconnects-capacity-hats-extensions-antenna-springs/nuts-3/8-24-by-1-inch/prod_129.html

They are really brass with a nickle plating. Also some 1/2" ID bronze sleeve bearings. (1/2" ID x 1-1/8" long) Why? Brass and Bronze are non-inductive, and this will be near the loading coils. I ground down the outside of the nuts to slip fit halfway into the bronze sleeves. The bronze sleeves were obtained from the local hardware store. You'll see why in a minute. I am the Grand Master of the bench grinder, almost. Fellow ham club member Frank, noticing my skint up knuckle said, "Why didn't you just slip the nut over a wood dowel and..." So NOW you tell me, Frank!

02 Soldered — Soldered together with torch, flux and solder, just like soldering copper water pipes. Cleaned up well after, scrubbing off all remnants of the acid flux. There were a few drips of solder inside, so I cleaned up those with a Dremel tool.

03 Ends Fitted — This is what they are for. These things will be epoxied onto the ends of 1/2" diameter fiberglass electric fence rod. I got the fiberglass rods from Kencove Farm Fence Supply. These are VERY cheap, about $2.50 for each 5' x 1/2" rod. You need two 2 1/2' pieces for each Buddipole.

http://www.kencove.com/fence/detail.php?code=F12-5SG

Length of the arms, from center of dipole (even with coax connector) to end of the hex nut, 31".

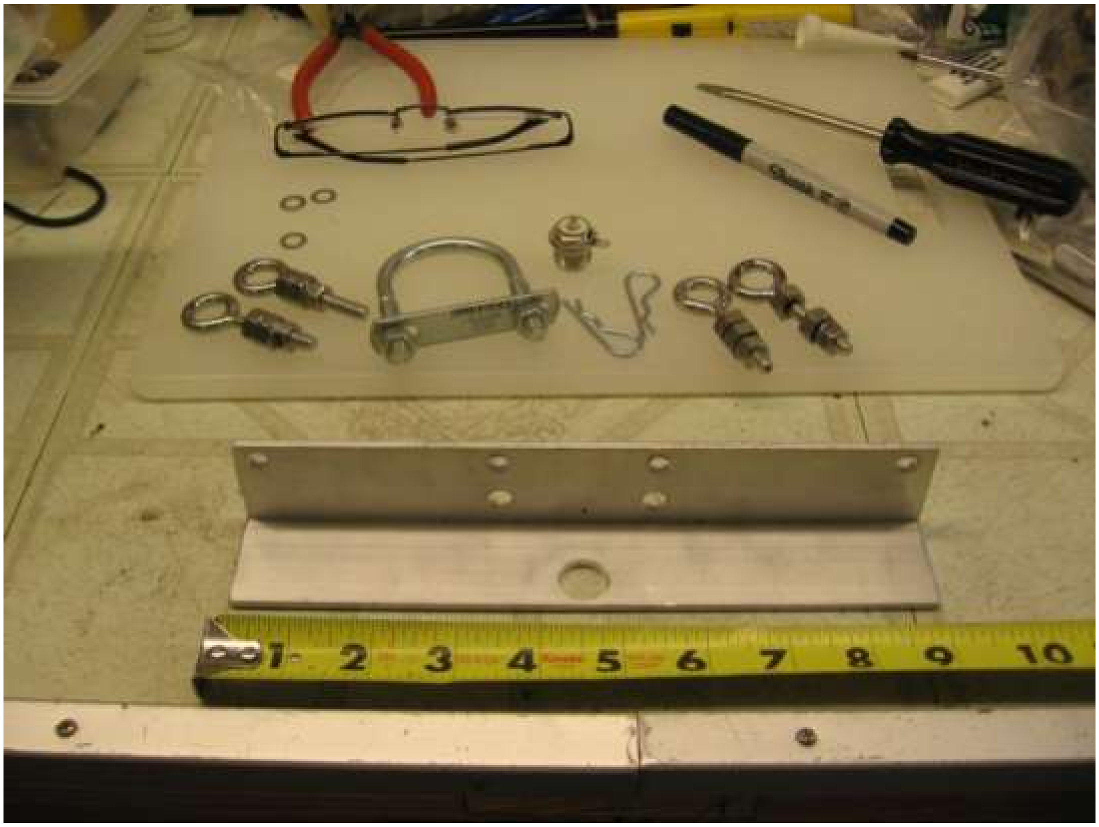
04 Whip Mounted — This is how it will go together. These black whips have a 3/8"-24 thread on the end, just like Hamsticks and other mobile antennas. And as luck would have it, they thread right into those nuts I soldered into the bronze sleeves and epoxied onto the fiberglass rods. The antennas droop. They all do, so get over it. These whips were obtained from www.buddipole.com for $18 each.

http://www.buddipole.com/lotewh.html

These are not the standard Buddipole whips, they are 9 1/2' long.* Along with the center sections, and by varying how much of the whips are pulled out, we should be able to bypass the loading coils and adjust the antenna to resonate on 15, 12, and 10 m.

With coils, this antenna should be able to be tunable to 80m, 40m, and 20m.

* MFJ has some 10' and 12' telescoping whips with the same 3/8"-24 thread.



05 Bracket. — This is a 9" long piece of 1/8" x 1 1/2" angle aluminum. I've drilled some holes. Big hole in center is to install a chassis mount SO-239 socket. Later some jumper wires about 4" long will be soldered to the center and ground tabs with Anderson Power Pole connector on the ends. You may use ordinary spades, or other connectors. I have a big bag of Power Poles here so I'm going to use them. They give reliable connection and are not at all fragile.

Anderson Power Pole connectors can be found here:

http://www.powerwerx.com/

You will also find a nice Power Pole installation tutorial here:

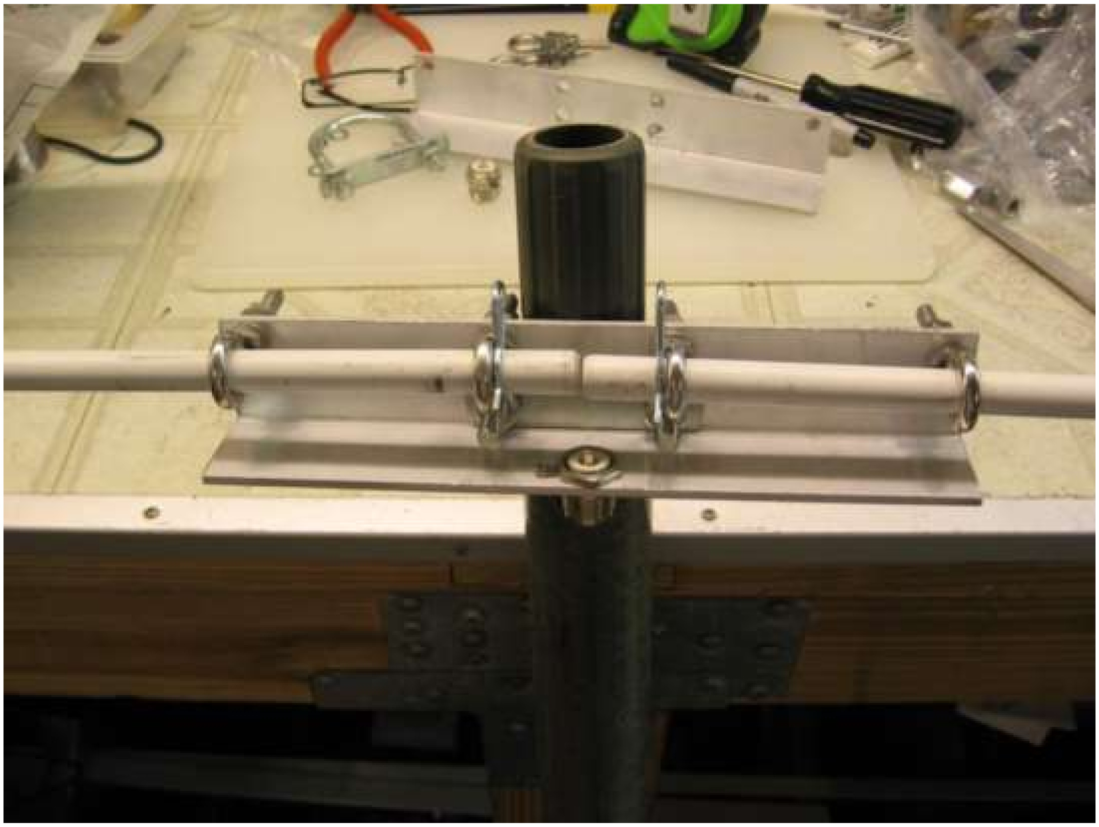
http://www.westmountainradio.com/supportrr_RC.htm

http://www.flyrc.com/articles/using_powerpole_1.shtml

In the background you can see some stainless eye bolts. There are two large nuts slipped over the shank of each eye bolt, and then the properly fitting nut. Those large nuts are used as just spacers. The reason is, there is an unthreaded section of the shank of the eyebolt and you could not get it tight with just the original nut.

The eye bolts go through the four holes across the top of the angle. It just so happens they have a 1/2" diameter hole. This allows those 1/2" fiberglass rods to fit through.

There is a U-bolt which will mount in the lower holes toward the center. This is also stainless steel, and will just fit around the top end of the mil surplus fiberglass poles you can buy on eBay.



06 Bracket assembled — I've cut the 1/2" fiberglass rods in half. They ended up being 3/16" short of 30" each. The ends with the nuts were epoxied on. Tomorrow I'll get some little brass screws, cross drill, and put in the screws to make sure the ends don't come off.

Those fiberglass rods ended up being 30 1/2" long overall, out to the hexnut on the end. We'll have a conductor run along those later to form the center section of the dipole.

You can see I have drilled a small hole in the rods, and they are held in place by slipping "hairpin" hitch pins through those holes.

I have installed the socket. Now it's starting to shape up.

The green fiberglass mast poles are military surplus ones you can find on eBay and at hamfests. They are 48" long. They are not really antenna masts, but are used to hold up camoflage netting. They sell for about $20 for a 12 pc set, with about another $20 or so for shipping. You only need about 4 or 5 of these mast pieces, so, split the set with a friend like I did.

Used masts
http://cgi.ebay.com/ws/eBayISAPI.dll?ViewItem&item=150315895044

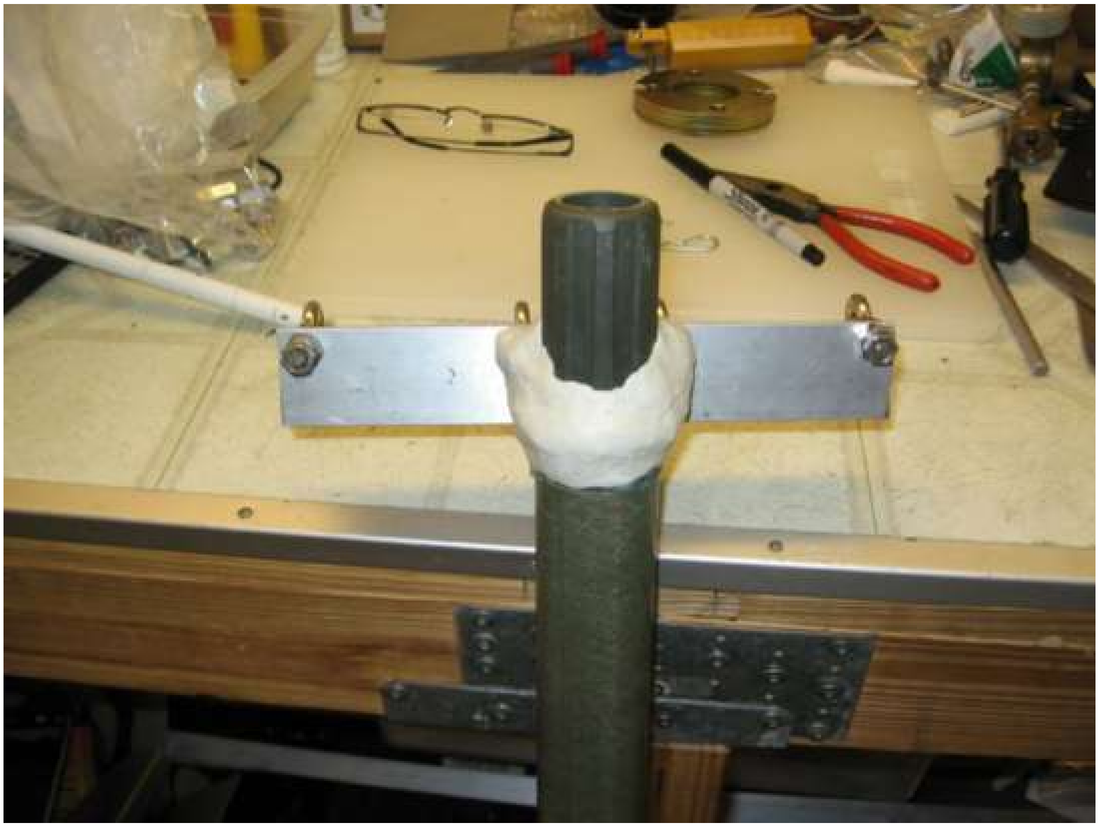
New masts http://cgi.ebay.com/ws/eBayISAPI.dll?ViewItem&item=150316253303

Everything is a little "loosey-goosey" right now, just finger tight. I'll take it all apart in a bit and reassemble with locktite on all of the nuts and bolts, and the nut on the SO-239 socket.

I'll use a Dremel cutoff wheel and cut off the excess threads on the eye bolts. Also, I will make the U-bolt only just tight enough to make the bracket snug. It is tightening around the plastic end of the mast tube. To keep it from shifting around, before I install the U-bolt for the final time I'll put a glob of epoxy putty between the pole and bracket. The U-bolt nuts will get an application of Locktite, also.

The bracket can be left on that top section for transport and storage. The arms come off, the coax comes off, there is no need for the bracket to come off.

First I used a Dremel fiber cut off wheel to remove the excess length of the eyebolts. I made sure there were no sharp bits left. I used plenty of Locktite to make sure everything stays tight.



07 Epoxy Putty.jpg — I put a wad of epoxy putty (similar to Plumber's Epoxy Putty, hardware store or Walmart item) between the bracket and the mast end. I snugged the U-bolt, but not so hard as to crack the end of the mast. You could tighten it all day and never get it tight enough to not wiggle. So, to prevent breakage, I just barely snugged it up, then packed epoxy putty around the back. Now it won't wiggle, it won't come off, and that part can just stay on that section of mast. No need to remove it.

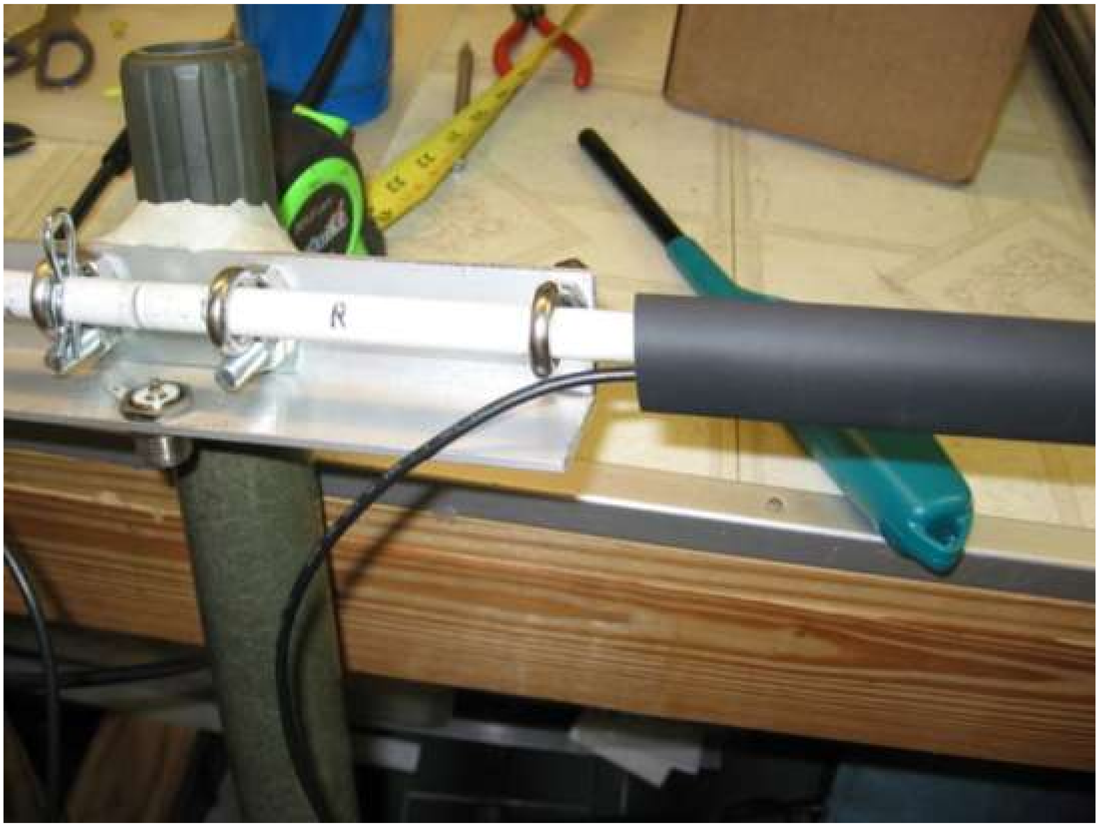
08 Teaser.jpg — This is a mockup, just a teaser to show you where we're going with this. Right now just one section of mast is slipped over the tube of PA Speaker Tripod Stand.

http://www.parts-express.com/pe/showdetl.cfm?Partnumber=245-010

These are somewhat larger, stronger than the ones sold with the commercial Buddipole. The fiberglass arms are installed, and the whips screwed on and extended. I will still have to make the coils, which will go on the ends of the fiberglass arms. Yeah, the whips sag. That can't be helped, and that is going to happen no matter what. Won't hurt a thing. But those fiberglass fence rods sure don't sag! That's some good stuff. Makes me want to look around and see what else I can make from them. There will be loading coils that will slip onto the ends of the fiberglass arms. There will be 14 ga wire that will go along the fiberglass arms to form the middle section of the dipole. Those antenna wires will be held onto the rods with heat shrink tubing. Anderson Power Poles will be used for all those connections.

09 Arm Terminals.jpg — I cross drilled and put in some #6 x 1" brass screws. Brass, all hardware brass because it is non inductive. Why? Because the loading coils for the lower bands will be nearby. I put a little glue on the screw, put it through. A little Locktite on the screw, a brass washer, and a brass nut. Then we have some binding post thumbnuts. Those are left loose. This screw does two things, pins the end nut assembly so it won't fall off, and it provides a way to complete the electrical connection to the telescoping whips in the ends.

10 Wiring Arms.jpg — Here some 14 gauge insulated wire is held in place with some short pieces of 3/4 heat shrink, shrunk in place. This 14 ga wire will be the middle part of the dipole.

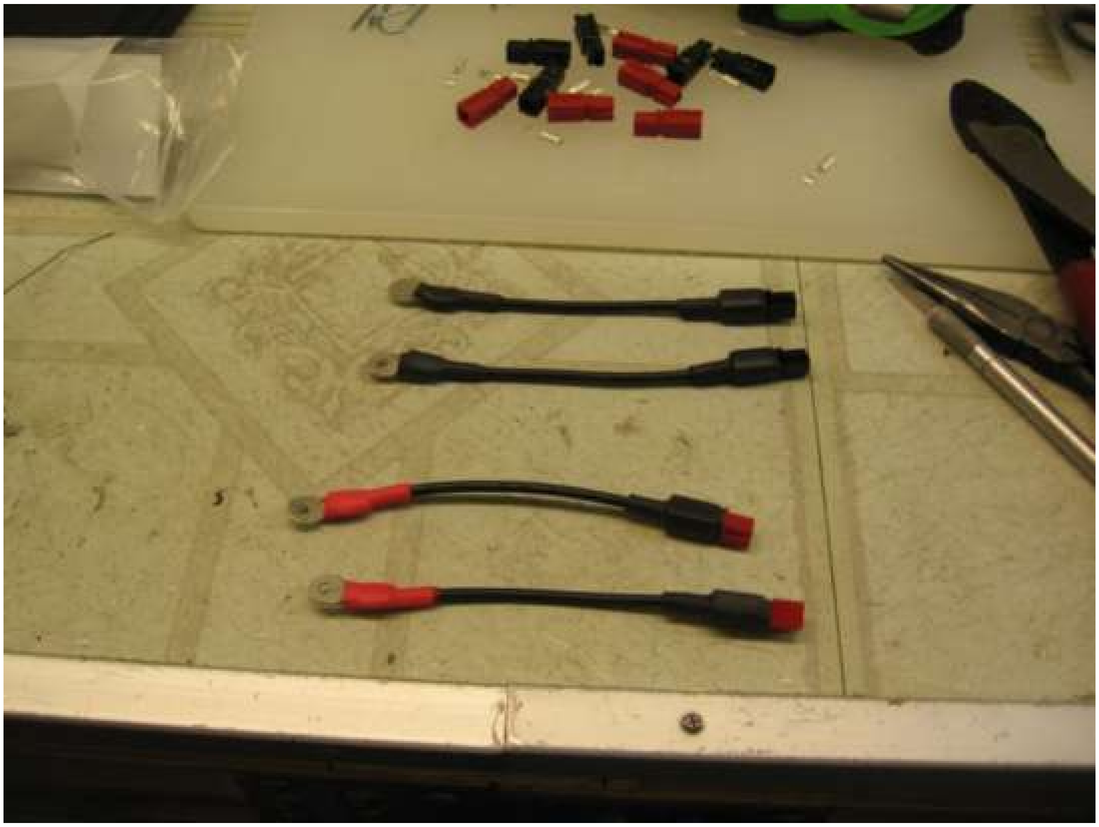


11 Heat Shrink Arms a.jpg — 3/4" heat shink is slipped over the fiberglass arms and wire, to about 1" from the end of the aluminum angle center support.

12 Heat Shrink Arms b.jpg — On the other end, the end of the heat shrink is about 6" from the outer end.

13 Heat Shrink Arms c.jpg — When I shrunk the tubing I did both ends first to anchor them in place, then worked toward the middle. Don't worry about trapping air bubbles. The air will easily leak out along the wire and rod. You will have to work the wire to be more or less straight, but even if the wire is a little crooked it won't hurt a thing.

Now we hook it all up.



14 Jumpers to Whips a.jpg — These are short, overall length 5". You only need to make up one red and one black jumper. I have two of each here because I am building two Buddipoles. These are made from the same 14 ga insulated wire as the center. Anderson Power Pole on one end and a #6 ring terminal on the other, with one of my favorite materials once again, heat shrink tubing!

15 Jumpers to Whips b.jpb — Power poles have been added to the pieces of wire coming out of the heat shrink tubing on the fiberglass arms. The gap between the end of the heat shrink on the arm and the nut on the end, where the whip will be screwed on, is where loading coils will be placed later on so that this antenna can be made to work on 20, 40, and 80/75 meters. Make the wire coming out of the heat shrink on the arm long enough to connect to the short jumper on the end. This is so that the coils can be bypassed, or not used at all, for use on 6,10, 12, 15, and 17 meters. For the lower bands, requiring the loading coils, those coils will have Power Poles on each end, too. Spade lugs could be used, but I like the Power Poles better.

16 Center wired.jpg — You can see here how I finished the center and connected to the arms with Power Poles. As you can see, we are now outside... somethings gonna happen!

17 Whips screwed on.jpg -- Screwed on and fully extended. The dipole is about 12' on each side.

18 PA Spkr Tripod.jpg — Heavy duty PA speaker tripod from Parts Express

http://www.parts-express.com/pe/showdetl.cfm?Partnumber=245-010.

19 Its UP.jpg -- There it is, up with 4 sections of mast, about 17' up.

23 and 26

I hooked it up to my Yaesu FT-897. It was getting dark and dew beginning to fall, so I didn't do much testing.

I turned the FT-897 down to 5 w power output with the coax connected directly to the output of the radio. With the whips all but the last segments extended, on 15 meters I had a SWR reading of 1.2:1. Hey! Not bad!

I checked SWR on 17 meters with the whips fully extended and got 1.6:1. Check ing 15 meters again, 2.6:1 with the whips fully extended. The tuner quickly had both bands down to 1.1:1.   I'm sure it will be tunable on 12 and 10 meters by simply pulling in the whips but I didn't have time to do that before it got dark.

In case you were worried, yes, this will blow over easily. But now I have some guy rings to attach to the mast used with bright orange (to hopefully prevent tripping) parachute cord and 1' long tent stakes.


28 It's up, 40 meter coils in use, and the whip ends adjusted for best SWR.

29 Closeup. The coils are just slipped over the ends, and the jumpers hooked to the coils. Anderson Power Poles used here, too.

30 Ferrite Beads. Four Snap On Ferrite Beads (FSB-1/4) from Palomar-Engineers.com were snapped onto the coax to act as a choke. These beads are for 1/4" cable, such as the RG-8X I used. Again, I have put bands of heat shrink tubing on the choke beads to make sure they stay snapped on.

I later added a 5th bead on the advise of Palomar Engineers. They also offer a ferrite choke balun kit.

31 Red Coil. The coil form is 1-1/2" pvc sink drain pipe. There are 28 turns close wound of 20 ga insulated wire. The is about 1-1/2" of wire from each end of the coil with Anderson Power Poles for connection. The "red side" of this dipole is connected to the center conductor of the coax. All Power Poles used are red, and the coil wire is red. This should give people a hint, red on one side, etc.

32 Black Coil. This coil is also on 1-1/2" pvc sink drain pipe. There are 24 turns close would of 20 ga insulated wire. Yes, good observation, the coils are not identical.   This coil is on the "black side" which is connected to the shield side of the coax.

Fine tuning of SWR is done by adjusting the whips. Just as the coils are not symmetrical, neither are the whip lengths. For 7.225 mhz, I came up with these adjustments for SWR = 1.3:1.

Red side whip, 5 1/2 sections, or 103" of whip pulled out.

Black side whip, 5 sections minus 3", or 92" of whip pulled out.

Probably a little better could be done, but I was happy with 1.3:1.

So, why are the coils assymetrical, and the whips pulled out to different lengths?

Good question, and one I asked myself.

When a dipole is up some distance, what, 1/2 wavelength? it is 72 ohms. Closer to the ground, as most people would put them, they are closer to 50 ohms, and a good match to 50 ohm coax.

But lower, such as this antenna will be used, the impedance will drop to around 30 ohms. By placing the feedpoint offcenter the antenna presents a higher impedance, closer to the 50 ohms of the coax. SWR can be lower in such a case.

Now, I thought, you've got to be kidding. At first I had both coils symmetrical, the whips pulled out equally, and sure enough, I had problems getting SWR below 3:1. I'd push both in or out a little, and get down to 3:1, then a little more, and it was back up 5:1 or higher. Then I just went with the flow, tried it like this, and sure enough, I was soon getting SWR's down, 1.9, 1.6, 1.4:1, and lower.

Make sure the knurled nuts (jumper binding posts from end of fiberglass to whips) are tight.

Coils for 20 meters were fabricated, using the same 1 1/2" pvc sind drain pipe. Red coil is 8 turns, 20 ga insulated wire close wrapped. Black coil is 6 turns.

For 20 meters, whips were, red side, 5 1/2 segments (total whip length 104"). Black side, 5 segments + 3" (total whip length 98"). This resulted in 1.2:1 SWR with tuner bypassed, at 14.240 mhz.

I tuned around and was hearing an old acquaintance from my SWL days, Angelo in Michigan, almost 1000 miles away, on 14.245 mhz. I waited for my turn, CQ'd him, and he came right back. We had a nice 25 min QSO. Signal report 59+15 both ways.

The next day I set up in the Park for an informal mini-field day.

Now I ask you, is that not a great picture? Bandstand, American flag, fountain on the left, playground in the background. Nice big shady oaks. Just a very relaxing place.

The Husky Power Center battery held up well for about two hours. From the Louisiana Gulf Coast I made a number of good QSO's, Iowa, Wisconson, Pennsylvania, Connecticut, Maryland, New York (a nice 25 minute chat about stereo gear, and he used to work at a TV station near me). Very good signal reports, too, from 56 to 59+20. This was all up on 20 meters.

By the time I shut it down, when I would key the mic the voltage would drop to 11.3 v, with 12.4 v on receive. Still, the radio did not shut down due to the low voltage. That was good. I don't know just how low voltage it will tolerate.

The Yaesu FT-897, LDG AT-897 tuner and antenna gave great performance.

The whips have 6 sections, and the left side (6 turn black coil) was pulled out to 5 sections plus 3" (total 98" whip length). The right side, (8 turn red coil) was pulled out 5 1/2 sections (total 104" whip length). The antenna, with the 20 meters coils, on 14.240 mhz gave an SWR reading of 1.2:1 with tuner bypassed.

Police cruised by and did not even slow down to look.

Talking on the radio in the park is fun.

Parts List

Fiberglass masts, carry bag, AND guy rings.

Used http://cgi.ebay.com/ws/eBayISAPI.dll?ViewItem&item=150315895044

New http://cgi.ebay.com/ws/eBayISAPI.dll?ViewItem&item=150316253303

—-

Tripod Stand

http://www.parts-express.com/pe/showdetl.cfm?Partnumber=245-010

—-

1/2" x 5' fiberglass rods, Item # F12-5SG. One required for one antenna, will be cut in half.

http://www.kencove.com/fence/detail.php?code=F12-5SG

—-

Hexnuts for ends of arms to mount whips

http://www.hamcq.com/whips-quick-disconnects-capacity-hats-extensions-antenna-springs/nuts-3/8-24-by-1-inch/prod_129.html

—-

Bronze bushings from the first photo are 1/2" ID x 1-1/8" Long. Hardware store item.

—-

9-1/2' long telescoping whips from Buddipole

http://www.buddipole.com/lotewh.html

MFJ also makes some 10' whips that will work as well.

—-

Anderson Power Pole connectors

http://www.powerwerx.com/

How to install Powerpoles:

http://www.westmountainradio.com/supportrr_RC.htm

http://www.flyrc.com/articles/using_powerpole_1.shtml

—-

Split Beads for 1/4" coax (get the size you need for your coax) FSB-1/4 fits RG-8X.

Use 5 beads or buy Palomar Engineer’s ferrite balun kit.

http://www.palomar-engineers.com/Ferrite_Beads/ferrite_beads.html

—-

SO-239 "chassis mount" socket

Heat shrink tubing - 3/4", 1/2", 3/8"

—-

Tent stakes, orange paracord, and other items can be found online.

Miller 570-T "Hi-Fidelity" AM Tuner
1942
J. W. Miller Company,
5917 S. Main Street,
Los Angeles, California, USA

In 1937, William N. Weeden published an article, in the February 1937 issue of Electronics magazine, describing a radically different TRF tuner using band pass circuitry to accomplish Hi-Fidelity audio on the AM broadcast band. Later the J. W. Miller Company took Weedens circuit, made improvements on it, and marketed it as the Miller model 570 tuner and model 570A receiver. These two models are one of the few TRF receivers commercially produced that incorporated AVC and a 10 KC filter. Miller marketed these units mainly for the use of professional broadcast monitoring by radio station engineers but it was also used by audiophile enthusiasts. Over time, Miller produced at least three versions of the 570 in which the only thing that mostly varied in each version was the dial and the tubes that were used. The tuner featured above, the 570-T, is of the third version of Miller's 570 series. It's audio responce is comprable to that of the 1953 Miller 595 "Hi-Fidelity" crystal tuner but it gets more stations then what the 595 can. Today these units are considered to be quite rare although not impossable to aquire. I aquired this tuner from an ebay auction in February of 2006.

Tube Line Up:
6SK7...1st. R.F. Amplifier
6SK7...2nd. R. F. Amplifier

Measurements:
Height...8.75 inches

Frequency Ranges:
BC Band...550 kHz - 1800 kHz

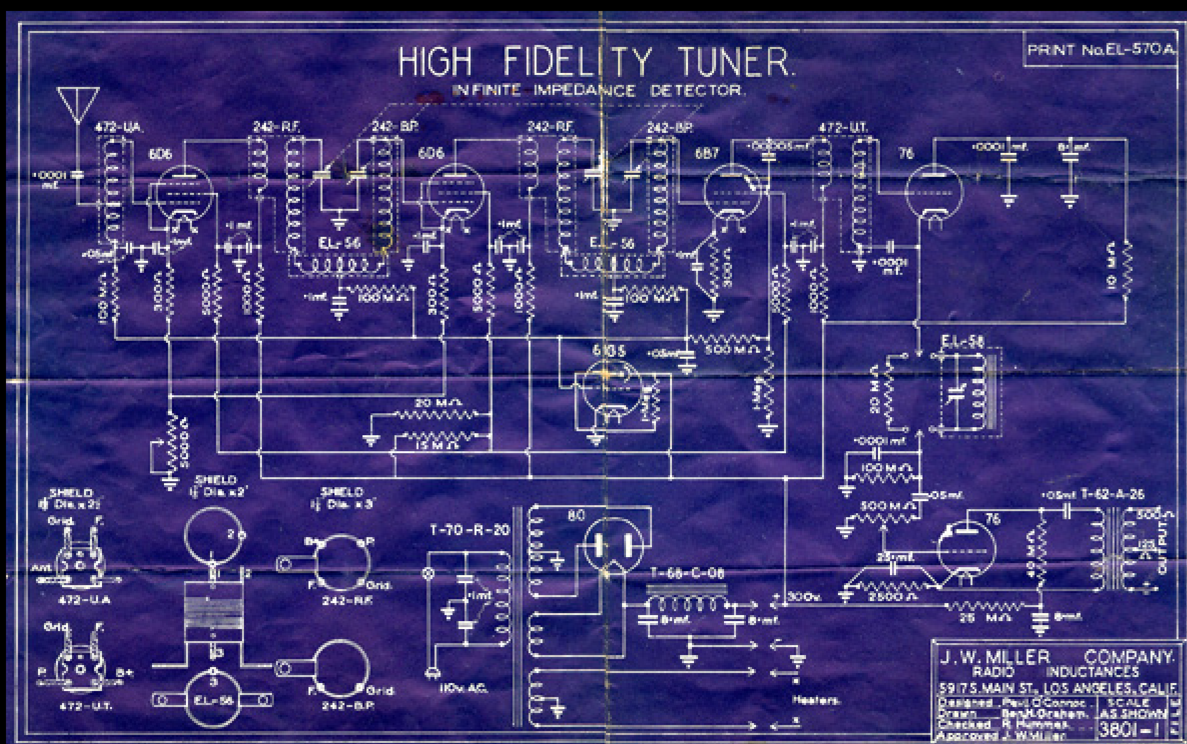
6SF7...Detector/AVC
6C5...1st. Audio
6C5...2nd. Audio
6E5...Tuning Indicator

Width...15 inches
Depth...12.25 inches

Power Source:
AC...110 Volts

Information and schematics for this tuner can be found at "John's Radio Pages" web site by clicking on the link below.

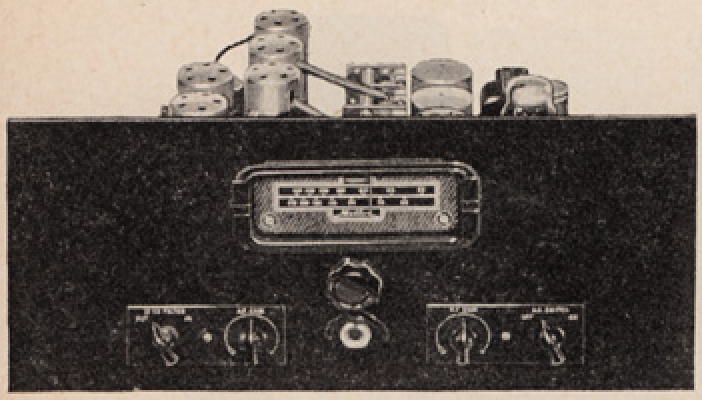
Schematic and Information



This is a blue print of the early version 570 which is the same as my set except it uses 5 and 6 pin tubes instead of octal tubes.

HIGH FIDELITY TRF COIL KIT

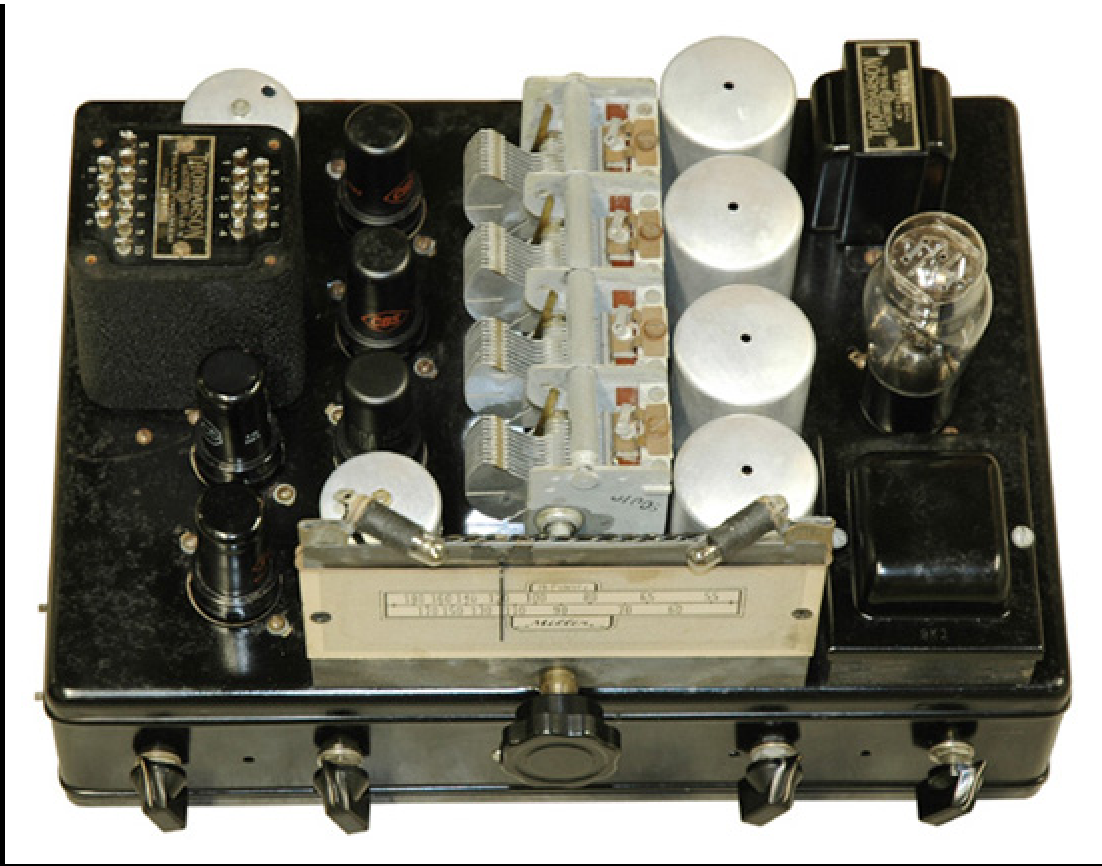
No. EL-570

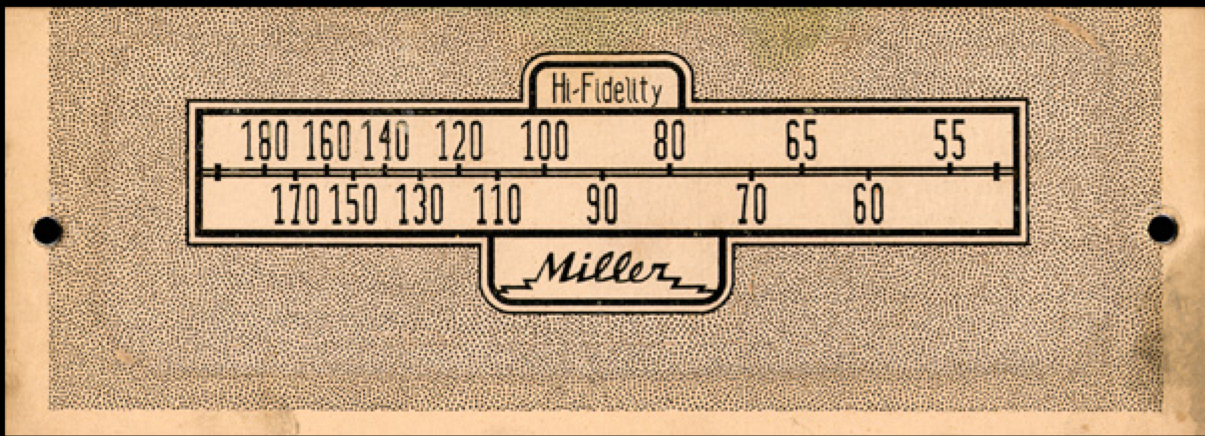


The Miller High Fidelity TRF Coil Kit has all of the coils and a 4-gang variable condenser necessary for constructing a true high fidelity receiver, using negative mutual coupled stages. If constructed according to directions, this coil kit will meet the requirements of the sound studio men for monitoring, and for making air check recordings of radio programs with all of their true and life-like brilliance as they are broadcast from the better radio stations. Complete parts list and instructions sheet with each kit.

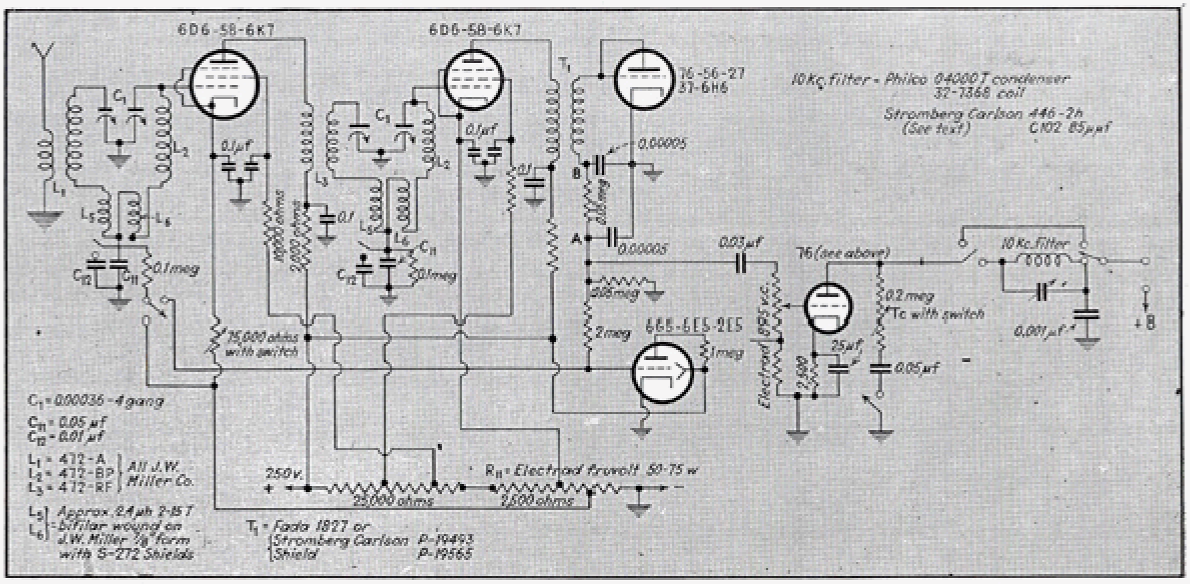
No. Items	Cat. No.	Type	List Price
1	472-UA	Untuned Antenna Coil	$1.25
2	242-RF	R.F. Coils (@ .90)	1.80
2	242-BP	Band-Pass Coils (@ .75)	1.50
1	472-UT	Untuned RF Coil	1.50
2	EL-56	Neg. Mutual Coupling Coil (@ .75)	1.50
1	EL-58	10 KC Audio Filter	2.25
1	2104	4-Gang Variable Condenser	5.00
1	EL-570-CD	Circuit Diagram	.25
	Total List Price No. EL-570 Coil Kit		15.00

Miller Quality Products Catalog
No. 40
Page 12





A Wide-band Tuner
By
W. N. Weeden
Electronics - February 1937
Pages 19 - 21



Circuit diagram, r.f. to output of first a.f. This tuner employs the selective circuits used in the well known Western Electric 10A receiver

Designed for reception of programs from local stations, this TRF tuner delivers sufficient output to drive push-pull 2A3 tubes, passes sidebands of approximately 7.5 to 10 kc., and has sufficient adjacent channel selectivity

This tuner was designed to meet the requirements of those who wish high fidelity radio reception from high power local stations. Many people have been in the market for a high fidelity receiver for some time but have not felt like paying the money for a one-microvolt, all-wave receiver when they wished to restrict their listening to not over a half dozen stations delivering several millivolts of signal. The tuner may also be used as a monitor for broadcast programs by advertisers or any others interested only in local programs.

The selective element is made up of 4 tuned circuits in pairs of coupled or band pass filter circuits. The coupling of negative mutual inductance and capacitance insures a sensibly constant bandwidth, which can be varied simply by changing the capacity of the coupling condenser. A diode detector is fed from this selective system through an untuned transformer. The detector is followed by a single stage of triode a-f amplification, which provides sufficient voltage output to load up push-pull 2A3 tubes through a proper coupling transformer.

The tuned circuits are overcoupled and exhibit the usual curve of peaks separated by a dip at resonance. This dip amounts to about 2 db and is not considered serious, considering the variation in response of the usual loud speaker. A 10,000-cycle filter made up of a tuned trap is located in the output of the first a-f tube. In this particular receiver, the trap can be removed at will, but in general it is advisable to have it in the circuit. On any good night in the New York suburbs the beat notes between stations makes it quite necessary to use the trap. With a 7,500-cycle side band an attenuation of 60-70 db is necessary to eliminate monkey chatter.

The diagram shows that the coupling impedance consists of a negative mutual inductance, a resistance and capacity. The negative mutuals must be wound by hand. For checking coil inductance and condenser matching, a simple test method is to make the coil or condenser section under test part of the oscillatory circuit of a simple oscillator. The simplest battery-operated, unshielded oscillator will serve although it is preferable to include a variable condenser of 15 to 25 micro-microfarads in parallel to the main oscillator tuning capacitor. With this auxiliary condenser set at midscale the main control may be varied until a beat is produced with a broadcast station (picked up by the receiver) at approximately the frequency desired for the test.

By cutting the various sections of the tuning condenser into the oscillatory circuit, it is possible to retune to zero beat by the auxiliary condenser and the discrepancy in capacity

may be readily noted. By bending plates it is possible to bring the capacity back into line. As most midget condensers are of the straight-line capacity type the capacity per dial degree can be calculated roughly. Coils may be checked by a similar method. The accuracy of alignment by this method depends upon the patience of the operator. An accuracy of 0.1 per cent is not unattainable.

The interesting circuit using the negative mutual inductance was first described by E. A. Uehling in Electronics, September 1930, and was used commercially in the well-known 10-A wide-band receiver of Western Electric. That receiver, however, used a square law detector so that modulation peaks affected the AVC action. The present tuner utilizes a linear detector, the AVC operates only on the carrier and is unaffected by the modulation. When the AVC is removed for manual r-f gain control, modulation does affect the input to the tuning indicator (6G5 on the diagram) so that a slight wavering of the shadow is seen. This does not bother the tuning, however.

Additional data on the negative mutual inductance coupling circuit may be found in the "Radio Engineering Handbook," 2nd Edition, page 158, ~ in Wireless World, February 18, 1931, and in Radio Engineering, December 1936.

Because this tuner was to be operated by an engineer several controls were placed in it, which would not be necessary or desired, perhaps, for more general use. For example the slight amount of AVC secured from the detector is fed back to the first stage and a switch makes it possible to remove this voltage and to control the r-f gain of the receiver manually. Selective fading seems to be tolerated with somewhat more enjoyment when the receiver is not under AVC. A tone control has been included in the receiver but has never been used by the engineer for whom the set was made. When static is so bad that a tone control is necessary, receiving is no fun anyhow. For general use the tone control might as well not be included.

The second r-f stage must be operated with sufficient bias, say 7 to 9 volts to prevent amplitude distortion when it is supplying 60 volts peak at 100 percent modulation to the diode circuit, the impedance of which is about 50,000 ohms. The audio frequency stage is conventional except that its grid is connected to one-half the diode load to improve the modulation capability of the detector. If insufficient output is secured, the a.f. may be connected across the entire diode load. When 20 volts are applied to the diode, approximately 100 volts (rms) will be applied between the grids of a push-pull amplifier when fed by a 2-1 transformer from the first a-f stage.

There are two untuned transformers available. Both are replacement items and may be secured from jobbers or factory branches handling these lines. One is a Fada unit, which gives somewhat greater output above 1200 kc., and the other is a Stromberg Carlson unit, which is slightly more efficient below 650 kc. The Fada unit is more compact. In such a receiver it is necessary to reduce as far as possible any chance of noise entering the circuits. Grid and plate leads must be short and direct; separate leads should run from each brush of the gang condenser, a single point on the chassis should represent ground for diode and a-f stages. This point should be near the diode.

After antenna, ground and power supply have been connected, the 1st r-f screen voltage should be adjusted (by moving clip on Electrad Truvolt voltage divider) to 125 and the cathode to plus 3. Then the 2nd 6D6 screen voltage should be set at 125 to 150 (depending on signal strength) and its cathode to plus 8 volts.

Then, with micro-ammeter or magic eye, proceed to align or trim the gang condenser (Wholesale Radio Service YH9705) at 1400 to 1500 kc.

After aligning carefully, the screen voltages may need to be reset so that with AVC operating, the weakest of the local network stations will impress 8 to 10 volts across the diode input (80-100 microamperes through the 100,000 ohm load).

If the AVC fails to hold down the signal with greatest field strength to 20 volts, readjust screen-grid voltages, and if no satisfactory compromise can be made-shift the AVC connection to point B from A, thus impressing twice the control voltage on the first r-f tube, at the expense of a slight increase in harmonic distortion. Although these adjustments may

sound tedious, it will probably be found that they can be accomplished in less time than that necessary to read this portion of the paper.

Although the diagram shows the 10,000-cycle filter (Philco) in the first a-f plate circuit, experience has shown that a Stromberg Carlson filter is somewhat more satisfactory. It is higher in impedance and should be placed in the diode load. The connecting leads must be very short.

With coils as described and coupled with condensers of 0.05 μf the bandwidth is approximately 20 kc. and when shunted by an additional 0.01 μf this bandwidth becomes approximately 15. The coils are special and to the best of the writer's knowledge may be obtained only from J. W. Miller Co., 5917 South. The loud speaker presents a problem. There are several fine speakers now available which are satisfactory up to 6000 cycles or so, but the writer has found that it takes one of the few double-unit speakers to really make a wide-band tuner show up its capabilities. The natural resonance of the cone of the speaker should be in the neighborhood of 30 cycles, if possible. This calls for one of the 18-inch or similarly large dynamic types with plenty of field excitation. Many listeners state that they find little advantage to extending

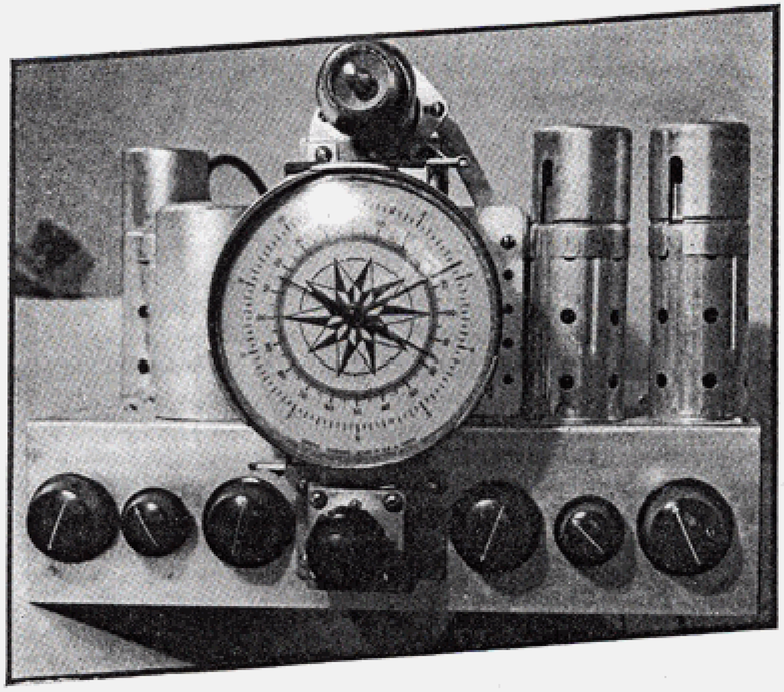
Main St., Los Angeles. While it is desirable to check the inductance and the capacity of the several units, it is true that reasonable variation between values of the several units will not cause great departure from symmetry of resonance curve nor appreciable change in fidelity.

A Yaxley switch may be employed to change not only the bandwidth but in the narrower position to insert the whistle filter as well. This refinement is unnecessary unless using loud speakers, which are flat to 10,000 cycles or better. With most single speakers, even the so-called high-fidelity units, sharp cut off usually takes place between six and eight thousand cycles, and little or no difference will be noted between a 7,500 and 10,000 cycle band width.

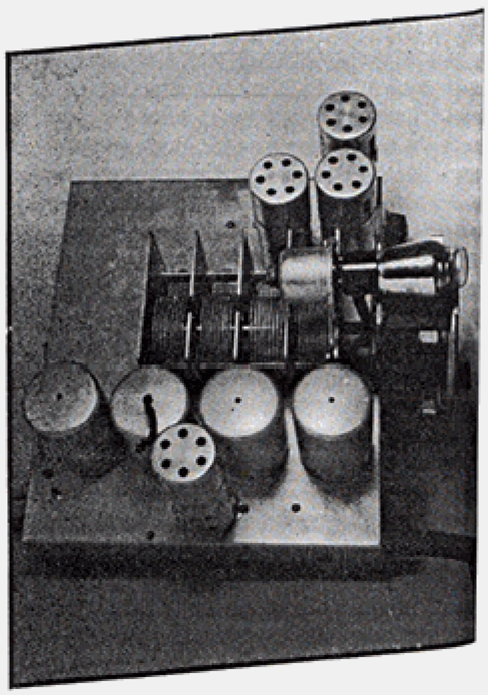
This tuner has been designed to operate with an efficient signal collector, because wide-band reception is worthless unless the signal to noise ratio is high. The antenna should be at least 20 feet away from wiring, other antennas, metal roofs, gutters, etc., and as long as possible -at least 75 to 150 feet. A good ground plus a noise-reducing leadin or transmission line with a transformer at each end are very desirable. A metal cabinet to prevent direct pick-up by leads or condenser stators will be desirable.

The loud speaker presents a problem. There are several fine speakers now available which are satisfactory up to 6000 cycles or so, but the writer has found that it takes one of the few double-unit speakers to really make a wide-band tuner show up its capabilities. The natural resonance of the cone of the speaker should be in the neighborhood of 30 cycles, if possible. This calls for one of the 18-inch or similarly large dynamic types with plenty of field excitation.

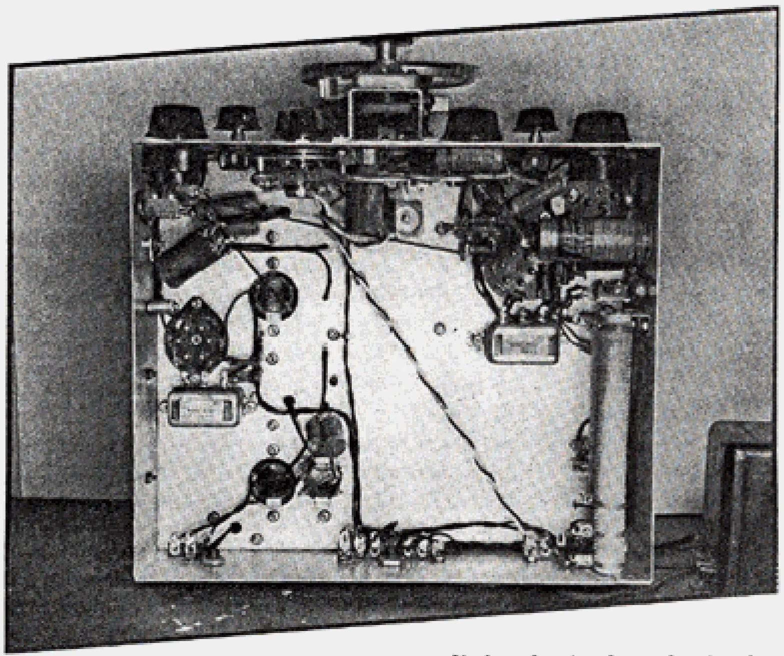
Many listeners state that they find little advantage to extending the audio range into the high frequencies unless the low end is extended at the same time. Thus a small baffle with a cut-off near 100 cycles is distinctly not good enough for faithful reproduction. The several acoustical systems recently developed-such as the labyrinth of Mr. Olney, the resonant pipes of RCA Victor, the resonating cones of Philco or the "bass reflex" principle of Hugh Knowles of Jensen-may be effectively employed. In the latter system, use is made of ports in the speaker cabinet, which are approximately resonant in the extreme low frequency range of the cabinet so that in relation to the cubic content, the phase of the back radiation of the cone is reversed.



Front view showing dial, knobs controlling gain, tone, etc.



View of the chassis showing general layout



Under chassis photo showing how little is needed for a local receiver

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This web page was last updated: May 10, 2007

My Model 75 Troy Radio

A comprehensive story containing historical, educational, technical and biographical elements & opinions for your entertainment by John Fuhring

Introduction

The Troy Radio and Television Company was a relatively small radio manufacturing enterprise once located at 1144 South Olive Street in Los Angeles, California at a location that is now the parking lot for the AT&T business center. The Troy Radio Company was one of hundreds of small American radio manufacturers that successfully tapped into the thriving market for radios during the era of The Great Depression. They were not a major brand and I think it is unlikely that their radios sold very far outside of Southern California, so perhaps that explains why there is precious little information generally available regarding this company and its products. Be that as it may, I will present what I know and I will describe for you my own Troy radio.

While searching for information on my radio, I couldn't help but wonder why this company had the word 'television' in its name. This is pure speculation, but I am of the opinion that the people behind the Troy Radio and Television Company may have been inspired by the early (1920's) television work done by so many brilliant scientists and engineers, including Philo Farnsworth. I am sure that the engineers at Troy Radio and Television expected television technology to quickly blossom forth just as had other forms of early 20th Century electronic technology, but in fact, television lagged for a long time because suitable camera technology was slow to develop. That, in addition to all the legal fights over patent rights really slowed things down. I also suspect that RCA's Sarnoff, because of perceived threats to his very lucrative system of AM broadcasting networks, threw in a lot of roadblocks, just as he had obstructed the development of Armstrong's FM system.

By the mid 1930s, it looked like television technology had matured to the point where there would be a real demand for television sets. Indeed, the 1936 Berlin Olympics were broadcast over TV in Germany, but World War Two and the need to militarize the electronics industry, put an end to commercial television until some years after the war was over. The rise of the commercial market for television products came too late for the Troy Radio and Television Company just as it had for the Farnsworth Radio and Television Company, so in 1941, just as the war began and just nine years after building their first radios, the Troy Radio and Television Company of Los Angeles went out of business.

I sometimes wonder if the birth of "The Age of Television" would have occurred five or ten years earlier if it hadn't been for World War Two. Generally we think of warfare as a great stimulator of technological advancement, but I think that it is obvious that both WW 1 and WW 2 actually retarded the advancement of radio and allied technology. It was only later, during the "Cold War," that massive government spending on various "defense" programs resulted in the development of micro-electronic, digital and Internet technologies.

My beautiful Art Deco Model 75 Troy Radio, circa 1936.
It is my opinion that smaller, AM only radios such as this one,
were designed for and bought by people who wanted a nice looking
and nice sounding radio for a small apartment or bedroom, but that a radio
such as this wouldn't have been an average family's main "parlor" radio. Nevertheless,
this is a very high quality radio that sounds good and looks good and for over 50 years it has
decorated my bedroom as I am sure it decorated a similar room in its original owner's house.

During its short life, the Troy company produced dozens of models of radios including car radios, large console models, relatively small table models and even radio/phonographs. Their products ranged from extremely inexpensive and simple 4-tube Tuned Radio Frequency (TRF) sets for city dwellers, to very elaborate and sophisticated consoles containing many tubes for their wealthy customers. In other words, they built radios for every taste and budget and successfully went head-to-head with big brands like RCA, Zenith, Philco, GE and others - at least in Southern California. Despite their wide range of products and despite their name, they never produced a single television set (that I know of). I think that the key to Troy Radio's success is due to the fact that they began selling their first radios in 1932, just as the worst effects of the Great Depression were being felt and when people were eagerly turning to the radio for affordable entertainment and relief from the worries of the day. Being a local manufacturer, they could save on transportation cost and those middle-man fees that plagued the better known brands and by offering a product of equal quality at a lower price, they experienced almost a decade of success.

As were all the radios of this era, the Troy radios were built with each component expertly soldered in by hand and to a design technology that allowed few cost reductions in manufacture. In addition, radios of this era were as much works of art as they were utilitarian and to a greater or lesser degree, they reflected the "Art Deco" styling that was so popular then. A radio had to have grace and style in a pleasing wooden cabinet, or it wouldn't sell. These hand made radios and their cabinets were built to high quality standards with what was then expensive high-tech components so that (by today's standards) these radios were by no means cheap to

manufacture.

To make matters worse, RCA and Hazeltine held all, and I mean ALL the patents for every single circuit and component in these radios. A license from RCA wasn't easy to obtain nor was it cheap, David Sarnoff made sure of that. It is my estimate that a small radio such as mine would have originally sold for about $20 and in today's money, that would be the equivalent of $400 to $500. In the 1930s, credit cards did not exist, wages per hour were in cents, not dollars and we all know how little money people had to spend in those days. A family or individual would have had to save long and hard to buy one of these radios, but the "Golden Age of Radio" had begun and regardless of their financial condition, everybody had to have a radio. For many Californians, for reasons of price, quality and style, their radio would be one of the Troy models.

How I got my Troy radio a long time ago

This story is about an actual Troy radio, my radio, a radio that I received as a present from my parents about the year 1959. This story is also briefly autobiographical because it is part of my fun to write about personal and historical details than are not usually found in articles of this sort. The following then is the story of the events that led up to me being given the radio as a gift.

After a long career as a Naval doctor, my dad retired to a little town along the central coast of California and went into private practice. Why my dad chose this Podunk place is a long story and beyond the scope of this essay, but I and my family ended up here for better or worse. Like all doctors, my dad had a "waiting room" where his patients would show up for "appointments" and then be made to wait and wait until he could see them. Maybe that's why doctors call their customers "patients" as a kind of cynical doctor's joke. Yes, people have always had to wait in doctor's offices and for several reasons - because some patients take more time to examine that originally estimated, but mostly because a doctor needs to have a full office and a surplus of patients in case somebody doesn't show up for some reason. Hey, it's a business, businesses need to make money and doctors will tell you that they aren't in it for their health -- that's a "patient's" joke, by the way.

So, what did my dad's patient patients do to while away the hours until the he could see them? They did just what they still do today, they read old magazines. To obtain these magazines, my dad's staff took out multiple subscriptions to all the popular journals of the day including Popular Mechanics, Popular Electronics and Popular Science. As their names imply, these were very .. ah.. popular magazines especially with men and boys. You have to realize that this was still a time in America when people built things and manufacturing was thriving. You have to realize that this was still a time in America when inventors and not money managers living extravagant life-styles were popular heroes. In short, we as a Nation had not yet become "cool" and "hip" and many of us were oh-so "square" and (as we say today) "nerds."

Being a junior nerd myself and having "The Knack" in its fullest expression, I just loved to get the old magazines from my dad's office when the new issues would arrive to replace them. I loved to read the articles and, what is more, many times I'd build the projects featured in the articles. These magazines were my nerd's lifeline that rescued me and offered me temporary refuge from all the "normal" people I was surrounded by all day, every day.

Popular Electronics, Popular Science and even Popular Mechanics magazine would, from time to time, have an interesting article about old shortwave radios and how to get them working again. From this I learned that starting in the early 1930s, the country experienced a shortwave craze and in response to that craze, the majority of the larger parlor radios and even many of the table-top models had at least one shortwave band. Well, even at my tender age, I too was caught up in my own shortwave craze and I eagerly sought out an old radio for my very own. In the meantime, several people told me they had old radios that didn't work anymore, so I started a little business and fixed up several old radios with new tubes and capacitors. Oh yes, by this time I really knew my way around an electronics parts store.

Being the Dilbert that I am, I talked and talked about these old radios and had everybody, including my parents, enlisted to be on the lookout for one. The problem is, I didn't understand that other people were not necessarily as technically minded as I was and that almost nobody but me was into this sort of thing. I didn't realize that nobody else in my immediate circle of family and friends knew the difference between an old radio with and an old radio without a shortwave band. My mom was somewhat of a "technical" person, but she really did not understand electrical things and of course, as skilled as my dad was with a fine scalpel and other delicate instruments of eye surgery, he really didn't know (or want to know) which end of a hammer or screwdriver to use -- and that's the truth.

Now, where was I? Oh yeah, I was telling about having people look for old shortwave radios for me. During the period of the late 1950s there were some 'antique' stores in Arroyo Grande (about 20 miles from here). Of course I use that term "antique" rather loosely because those stores sold mostly 'j-u-n-q-u-e,' and sometimes they sold old radios too. One weekend my mom and dad drove up there just to look around. While up there, they saw and bought an old Troy radio for me. I'm sure my folks remembered listening to similar radios as young people and so they must have thought that this radio was one I would want.

When they got home, they presented the radio to me and at first I was absolutely delighted and a little overwhelmed with pleasure at seeing it (you know what they say: "simple minds, simple pleasures"). I peered in back of the set and saw that it was filled with these huge very, very old fashioned looking tubes, so I knew I was going to love the radio. I plugged it in and turned it on expecting to hear nothing but a loud hum, but to my surprise, the radio came to life after a short warm-up. The radio played beautifully --- on AM -- on AM ONLY.

Oh no!! My parents had bought me a useless AM radio that did not have a shortwave band. I was dreadfully disappointed, but considered it extremely ungrateful and ungracious to let my disappointment show, so I kept up my enthusiasm out of a sense of appreciation for what my parents had tried to do for me. In the weeks that followed, it was apparent that the Troy radio wasn't what I wanted, but at least I had a nice decoration for a shelf in my bedroom. It was shortly after this I found a Philco Baby Grand radio in a trash can and it had a shortwave band. That radio became my pride and joy until I realized that the one shortwave band it had was kind of useless too because it didn't go above the 80 meter band. A year or so of pining for a "real" shortwave radio finally resolved itself when my parents bought me a Hallicrafters S-120 radio and, if you are interested, I have written the story of it here on my website.

What my Troy Radio is and is not

Before I put the radio on its shelf for its long wait and while I was still experimenting with it, I made some guesses regarding its technology and guesses regarding how old it was. Those guesses turned out to be quite incorrect, but I held them as "fact" for over 50 years.

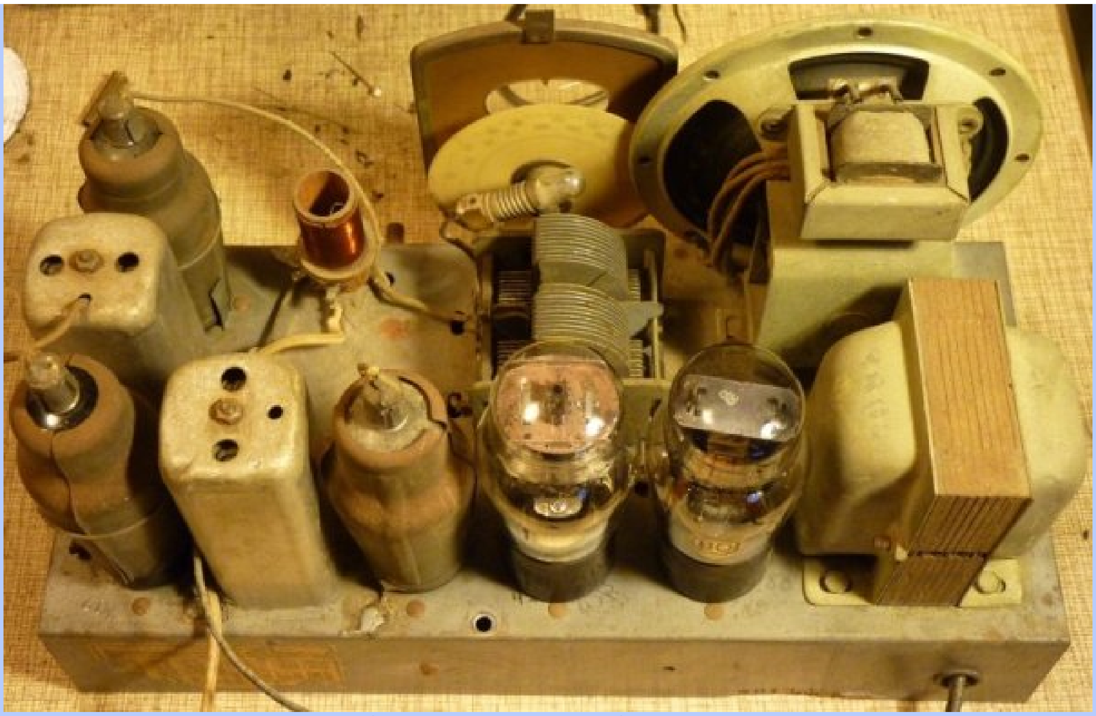
So, how did I come to make such incorrect guesses? Well, thanks to the articles I had read in all those magazines, I knew that really early radios operated not on the 'superheterodyne' principle, but on the older 'tuned radio frequency' (TRF) principle. I also knew that many of the TRF radios had a "regeneration" control which made them perform as well as a more complex superheterodyne, but also made them squeal. As a TRF radio should, my radio squealed when I rotated (what I later found out was) the tone control and my mom even commented that she remembered how early radios used to squeal like that. Further proof that I had a TRF radio was the fact that, in my young life, I had never seen tubes that looked so big, looked so odd shaped or tubes that were so densely packed together or had such old fashioned pin type bases. The final proof was my mistaken belief that there was only three tubes besides a rectifier tube. I knew that you can not have a superheterodyne radio with so few tubes and therefore with all this circumstantial evidence, I concluded that I must have a really old, old TRF radio. Now, if I would have taken the trouble and removed the chassis from the wooden case, I would have spotted the mixer tube buried in front and I would have known it was a superheterodyne, but the radio worked so well, there was no reason to take it apart.

Rear view of my radio.
I had no idea there was another tube up front, so I thought I had a TRF radio.
There is nothing on the chassis or case identifying the model number,
so I was at a loss to tell just what model I had.

My Troy goes on the shelf for 52 years

My Troy was built just for the AM band. It was without shortwave and therefore, to me, it was kind of useless, but it was nice looking and that art-deco dial with the stylized picture of the Trojan Warrior and the two "Spirit of Saint Louis" style airplanes near the bottom of the golden dial really appealed to me as being very pretty. If nothing else, the radio made a nice decoration for my bedroom, so I put it on a shelf below my window and there it has graced that room for 52 years until just yesterday (December 20, 2011). I left home after high school, I served in the military during the Vietnam War, I attended university and lived in Nevada many years, but bought the family house after my parents died so that when I returned to my old room as an adult, the radio was still there in the very same place. From that time until just yesterday, the radio has remained in its old place.

Yesterday I removed the radio and then, for the first time, I took the chassis out of its wooden case so that I could restore it electronically and write up yet another boring story for my website. When I took it out of its case, I was in for a big surprise. As I mentioned, all these years I had been under a mistaken notion that my Troy radio was a very ancient TRF radio, but in actuality, it was a more modern superheterodyne and the really old looking tubes weren't as old as I had thought. I must be really weird because I just love to discover the truth behind things, especially things that I've held as "fact" most of my life when, in fact, I was completely mistaken all those years. I don't know how to describe it, I just have this kind of "OHMYGOD(!!)" feeling that makes me want to laugh at myself.



With the chassis out of the case, I was in for some surprises as I learned that notions I had held for 50 years and more were mistaken.

As I have indicated, I was in for a lot of surprises when I removed the chassis from its case for the very first time. First, it was immediately obvious that my radio was NOT a TRF radio. It had two IF cans (one of which is clearly visible from the rear and which I should noticed as a kid) and it has a fifth tube that could only be the mixer/oscillator tube of a **superheterodyne** receiver. This tube is buried, out of sight, in front of the huge tubes to the rear and so I never noticed it all those years ago.

Oh my goodness (!), all the research I had done regarding the early Troy TRF radios had been based on my long held but erroneous assumptions and was now utterly, utterly moot. I had wasted all that time, even capturing schematics, but the radio wasn't a TRF and because its name-plate is missing, I had no idea which model I had. These radios are so rare, there are only a few Troy Radio pictures anywhere on the Internet and I couldn't find anything that even remotely resembled my radio, so I was at a loss. In desperation, I began to go through all the Ryder Schematics looking for something that resembled my radio's electronic design.

Getting a workable schematic for my radio

In other stories on my website, I talk about the importance of having a good schematic to work to, so I needed to begin a search to find out what model I have. Before I began my search, I inspected each tube and learned something about its type and function. The 6A7 is a "pentagrid" mixer/oscillator, the 6D6 is a "variable transconductance" IF amplifier, the 75 is a "diode-triode" detector/AVC/audio amplifier, the 80 is a full wave high voltage rectifier and the 42 is a audio power output amplifier. Knowing all this enabled me to look at many schematics and identify drawings that came close to my radio's actual design.

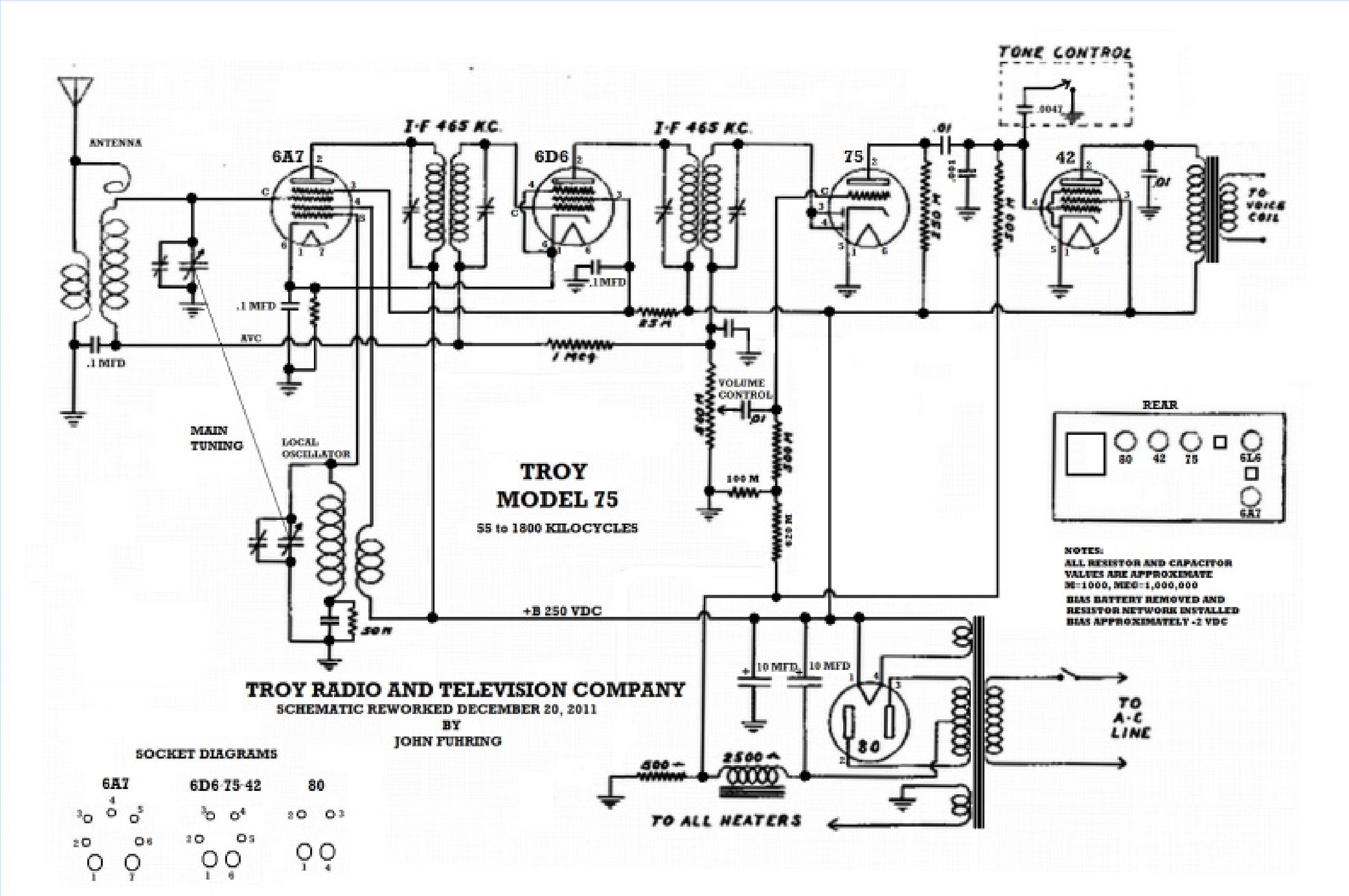
After looking at several early Troy Radio schematics, I initially concluded that I had a variation of the model 57. There is a picture of a model 57 on the Internet, but it doesn't look much like mine except the rear is very similar and it uses the same tubes except my audio output tube is a 42, not a 41. Finally, the triode section of my 75 tube is not biased with a voltage divider from the negative side of the power supply as shown in the 57's schematic, but is biased using a really strange looking device that I had never seen before and something I didn't have a clue what it might be or how it worked.

That mushroom-shaped yellow thing is a cell (battery) that was
used to supply the first audio amplifier's bias voltage.

Of course, after 75 years, the cell is dead and no longer puts out its negative 1.5 volts. I despaired ever finding out for sure what that thing is or what it was supposed to do. Since it is in the grid circuit of a very sensitive tube, I suspected it must have put out some kind of negative biasing voltage, but it seemed so absurd to me that they would use an electric cell for that.

Well, that's exactly what it was, an electric cell for biasing the 75 tube. I know that now because I found an Internet site that identified it as a 1.5 volt cell made by the Mallory Battery Company. Now, since this circuit draws no current, it is my guess that an electric cell such as this would last the expected life of the radio (10 years?).

Since the schematic of the model 57 seemed to match my radio so closely (except as noted), I captured it and began to redraw it to match my radio in every detail. Below is the schematic as I've so far developed it.



A model 75 schematic created from a model 57 drawing.

This drawing has been made to match my radio as it is presently wired and is actually a better drawing than any of model 75 schematics I found elsewhere on the Internet.

Notice that this is a simple, but very effective design made possible by breakthroughs in vacuum tube technology that had occurred not long before this radio was manufactured.

Finally identifying my radio's actual model number

I know that Google is pretty ethical about listing sites linking to pages that have been placed off limits by their "Robot files" so, in a brief flash of insight, I decided to search the Internet with another search engine that might not be so ethical. With Yahoo, I came up with a site that referenced an unindexed page that features pictures of a radio with a case that is similar to mine. What's more, it has a picture of a beautiful golden dial that is absolutely identical to mine. They identified their radio as a 1936 "Model 75" which means that my radio is almost surely a 75 too or a close variation of that model.

A picture of a very handsome 1936 model 75 Troy Radio from an antique radio article written by Mr. Michael Biddison and used with his kind permission. This radio's case is an even finer example of the Art Deco style than mine is.

Notice how similar this beautiful radio is to my radio in size and especially how utterly the same the dial, dial plate and the knobs are. My radio just has to be a cabinet variation of this model.

Notice too how compact this and my radio is. Most of the radios of this era were taller in the very popular "Tombstone" or "Cathedral" style with the speaker located far above the chassis and with a lot of empty, wasted space inside.

The Troy model 75 radio has the same size speaker and chassis as the taller radios, but will fit nicely and look better in a small room where it doesn't take up so much space. I am very much of the opinion that this model was designed specifically to be a lady's boudoir radio.

Knowing what I know now, I have to conclude that my radio isn't nearly as old or primitive as I once thought it was. Armed with this model number, I looked up the schematic of the model 75 and sure enough, everything matches my radio. The trouble is, all the schematic drawings of the model 75 look really terrible. Nothing I could find is nearly as good as the drawing that I have already created from the model 57's modified schematic, so that's the one I'm keeping.

The little mushroom-shaped thingey

By the way, the excellent article Mr. Biddison wrote about his own model 75 told me what that strange mushroom thingey was used for.

It is a -1.5 volt cell made by Mallory Battery Company, now known as Duracell, maker of the famous "copper top" battery. It seems that many radios of this age -- and not just the Troy radios, used this little 1.5 volt electrical cell to bias the first audio amplifier. I never would have guessed that anybody would use an electric cell for this because it seems to me to be such a foolish, expensive and complex way to bias the tube. My Fairbanks uses a voltage divider in the negative voltage supply and that is strange enough, but why in the world would anybody use an electric cell that can run down and go dead on you?? What an outlandish idea, but there it was.

Later radios simply use a high resistance grid bypass resistor that allows those passing electrons that hit the grid on their way to the anode to make the grid negative and thus "self-biases" the tube. This form of self-biasing works so well and it is so simple, but early tubes like the 75 don't sound so good when using this scheme. The fact is, they sound much better if a fixed negative voltage is used, like from a battery -- or from a voltage divider.

Since writing the above, I have found more information on the Mallory Bias Cell. The cell first showed up in radios like mine in 1936 and became very popular and it was anything but an outlandish idea. Since the cells were not required to draw any current, they did indeed last years and years. I even came across a website that claims that they were able to detect measurable voltage out of one that was 50 years old. What really made them practical was the fact that somehow they were cheaper than the resistors and capacitor usually found in more "conventional" kinds of biasing. Wholesale, they only cost about $0.15 whereas even one resistor would cost more. Finally, there is a theoretical advantage to using a highly precision and unchanging voltage for bias, but in all the experimenting I've ever done, it is impossible for me to detect the difference and when you consider that these were AM radios, the difference really is impossible for any mortal person to hear. Personally, I think these little things suck and they are not worth the few extra cents a resistor voltage-divider network would cost, but it is in the nature of manufactures -- following the principles of 'modernity' -- to cut every cent whenever possible -- even if it seems silly.

Something like this would cost about $3 in today's money

To replace the Mallory cell with a watch or hearing aid battery was simply out of the question so I initially put in a 6 megohm resistor and allowed the tube to self-bias as was done with more "modern" radios. This seemed to work great, but I did notice some harshness in the audio after playing the radio for a while. I also noticed that the anode resistor of the 75 tube was getting warm because insufficient bias caused the tube to draw too much current. After experimenting a little, I found that a fixed negative bias of about two volts makes the radio sound its best, so I tapped into the negative voltage where the filter choke coil is taken to ground by a resistor and I put in a simple voltage divider that gives me my negative two volts. How ironic that today resistors are so cheap as to be almost free while a little electric cell to replace the Mallory would be many times more expensive.

Anyway, I am so very pleased that I was able to find out what that little mushroom shaped thing is because not knowing what it was very much bugged me. As a precaution, I removed the button cell from its holder, but left the holder in because it provides a convenient place to mount the two resistors that make up the voltage divider I mentioned.

The utter simplicity and genius of tube radios

The following two photos are of the underside of my radio before and after I replaced its defective components.

A very uncrowded underside chassis.

As you can see, the old paper/wax capacitors have not yet been replace. Looking at this chassis with a detective's eye, it can be seen that restoration work was done in the late 1950s. Notice the two "modern" ATOMS electrolytic electrolytic capacitors that must have replaced the huge electrolytics of the early 1930s.

You know, one of the things I love about these old tube radios is the very genius behind how electron tubes operate. It is fascinating to me to see how simple elements inside these tubes shuffle electrons around so brilliantly. The schematics are so incredibly simple and when you turn over the chassis to look at the underside, there are so few components need to support the few tubes that are there. From the top of the chassis, the big tubes crowded together make it look like everything was squeezed together, but underside the chassis, it is mostly empty space.

Same view with the large old parts removed and tiny new parts installed.

This radio has three silver mica capacitors. Those and the resistors are in perfect working order (as they always are), so I did not replace them. After I took this photo I replaced the last paper capacitor seen in the lower right. All the new parts I needed to restore this radio electronically cost me less than $12.

By the way, even after 75 years, the four IF circuits are still in perfect tune and the dial calibration is still right on the money.

Out of its case, here is the front of the chassis showing the handsome art-deco dial, the new-looking speaker, the mixer tube and the antenna tuning coil.

Here is a close-up of the beautiful dial.
Notice the gold Trojan Warrior, the encircled Trojan Helmet and world globe with the words "TROY quality RADIO" emblazoned across them and at the bottom of the dial, the wonderful Lindberg "Spirit of Saint Louis" style airplanes.

To me this is an absolutely classical expression
of the "Art Deco" styling so typical of the 1930s.
Some radios of this era carried this to an extreme
but I believe that my radio expresses this quite tastefully.

A brief word about the vacuum tube technology used in my radio

When I first looked in back of my radio so long ago now, I was fooled by how large the tubes were and by their old fashioned base configuration. Their sockets were very similar to some of the very oldest tubes dating back to the early 1920s and so I naturally assumed that they must be very primitive and very simple type of tubes -- perhaps just one step more advanced than DeForest's Audion tubes. Well, I was wrong. As large as these tubes were and as old fashioned as their bases appeared, they were quite advanced tubes for their day.

The 6A7 is a pentagrid tube that is a younger brother to all the subsequent tubes of its type. Both the 6A7 and the 6D6 are sophisticated "variable transconductance" amplifiers and, in addition, the 6D6 is a pentode that had all the "inter-electrode capacitance" and "secondary emission" problems of earlier tubes solved. The 75 tube is a both a Fleming Valve type AM detector and a "high mu" audio amplifier. Although the 42 power amplifier tube predates the later "beam power tetrodes," it was a very nice and powerful pentode tube that was the result of some very clever tube development that occurred during the decade of the 1920s. All the tubes in my radio had come on the market not too much earlier and so they represented pretty much the "state of the art" in electronic design when my radio was new in 1936.

Because these tubes were so sophisticated, designing my radio around them allowed the radio to perform as well or better than the more expensive and prestigious radios that were designed with eight, ten or more of the older type tubes. I am sure that owners of slightly older radios would have been impressed with how small, but fine sounding my Troy was (and is). I am sure the original owners of my radio were delighted with how the radio was able to fill their apartment or bedroom with plenty of high quality sound when they tuned in one of the many stations broadcasting entertainment, sports or music of that era.

The old radio finally plays beautifully for me, but only after smoking up my room

Well, yesterday afternoon I decided the time had come to plug in the old radio and see if it still worked after 75 years. I must admit that I have become rather smug about my "first power after 50 years" rituals. Up until now, I have had 100% success and my old radios have all come to life as soon as they were turned on. A big part of that success is due to the detailed inspection of the entire chassis wiring and verifying that all work was done properly, so it isn't simply pure luck, but careful work. This time things went very wrong and my smugness suddenly turned to horror and panic.

What can be more horrifying to a Dilbert like me but to have their project start to smoke when first turned on?!? What can smell worse to a Dilbert like me than the stench of burning phenolic?!? Oh god(!!) the radio began to smoke and the room was filled with this horrible stench, so I quickly killed the power. I searched and searched for over-heated components, but couldn't find any. Completely baffled, I had only one recourse --- yes, I must give the radio one more "smoke test." I pulled out the rectifier tube so that the high voltage section wouldn't be damaged by a possible short and turned on the radio and again I got smoke, but before I turned off the radio I noticed a spark of light. I turned off the lights in the room to make any sparks more visible, situated myself close to where I thought I saw the spark come from and gave the radio a third "smoke test." This time I could clearly see that the 80 tube's (the high voltage rectifier's) phenolic socket was arcing and minor burning was taking place.

Those electrodes are quite close together in the rectifier's socket and they carry around 700 peak volts between them when the radio is first turned on. Over all these years, the insulation had obviously broken down there and as the phenolic turned into carbon, further breakdown occurred until a path for electricity was created. To fix it, I simply took my small grinding tool and removed all the carbonized material just as a dentist removes the decayed matter in a bad tooth. There was still plenty of good, undamaged phenolic material remaining to hold in the electrodes, so, unlike a tooth, there was no need to fill up the cavity with something that might itself cause future shorting -- it seemed to me that an air gap would be the best insulator under these circumstances, so I didn't bother putting anything in the cavity.

After I had everything fixed and the 80 tube back in, I gave the radio a fourth "smoke test" and I am very pleased to say that the old radio came to life after the usual short warm-up and without smoking this time. In

fact, the radio sounded wonderful, simply wonderful and much better than I expected a radio with such a small speaker. Perhaps I shouldn't have been so surprised. These old speakers have a thick and a very high quality cone that work as well as they do in large part because of the powerful electromagnet that is built into them. Cheaper speakers that came with later radios had weak permanent magnets that required a lighter and a larger cone for them to sound as good. By the way, this powerful magnet also acts as a filter (choke coil) for the high voltage power supply.

These old radios did not have built in loop antennas probably because America's population was much more rural than it is today and most people put up outside antennas (which work much better than loop antennas) anyway. I connected my newly refurbished Troy radio to my outside antenna and was extremely pleased to find that the AM band was literally filled with signals. As crowded as the band was that night, my radio was able to easily tune each station in turn and tune them in without any of them overlapping. For a simple AM radio, this radio tuned sharply, and its audio was just superb. At first the tone control didn't work because I hadn't wired it in. I wanted to experiment with different values of capacitance to find just the right tone and found that a 0.0047 MFD capacitor in the grid circuit of the 42 tube greatly reduces the high pitched noise on weak stations, but still gives the radio a very nice sound. In fact, even on strong stations, the slightly more base sound is very pleasant to listen to.

Conclusions

As mentioned at the beginning of this story, the Troy Radio and Television Company was a small player in the radio industry of the 1930s and they manufactured relatively few radios compared to the "big boys" like RCA or Philco. Couple that to the fact that only a tiny fraction of all the radios built during that era escaped being thrown away after they became obsolete and it is no wonder that today a Troy radio is so rare. I consider myself to be in possession of a radio that may not be a valuable or sought after collector's item, but one that still stands out from all the more common brands and one that is inferior to none of them with regard to beauty, technology or quality.

I now have a 75 year old radio that should be playing beautifully well into its next 75 years, but you know, I wonder if there will be a AM radio band 75 years hence? I know there won't be a "me" 75 years from now. Gee, if there was something else to listen to locally besides all the nutty right-wing "Hate Talk Radio" or the equally disgusting right-wing "Christian Radio" - I would be really happy. I sure hope that KGO up in San Francisco never goes off the air because if it did, nothing good or worthy would remain to listen to on AM -- in my opinion.

THE END OF MY TROY RADIO STORY (FOR NOW)

Having arrived this far, obviously you have a superior attention span and reading ability that far exceeds that of the
majority of web users. I highly value the opinion of people such as yourself, so I ask you to briefly tell me:

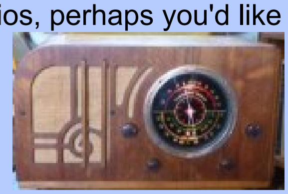
Did you enjoy this article or did it suck?

Please visit my guest book and tell me before you leave my website.

If you have an antique AM radio and you need something decent to listen to, perhaps you should buy or build your own

Low Power AM transmitter

If you liked this story and love old radios, perhaps you'd like to read the story of my beautiful 1936

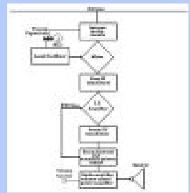


Fairbanks Morse Radio

Recently I found and restored a 1938 Crosley Super 8 radio that was from a posponed repair job 50 years ago

[Please go to my Crolsey Radio Story]

If you are interested in learning a little about how this and other old radios work, you might be interested in



An essay on Armstrong's Superheterodyne Principle

I have lots of other stories about my wonderful old tube radios that you might enjoy, so

Please go to the radio page and select another radio article

My website has a lot of other stories and articles that you will find links to on

My Home Page

DIY Audio Home

Files for "A Single-Ended E-Linear Amplifier" from AudioXpress 04/05

Here you can download some supplementary info and files for the E-linear amplifier published in AudioXpress magazine, April, 2005. The article isn't posted here - please go buy a copy of AudioXpress to get the full story!

Here's the Schematic (31kB PDF file)

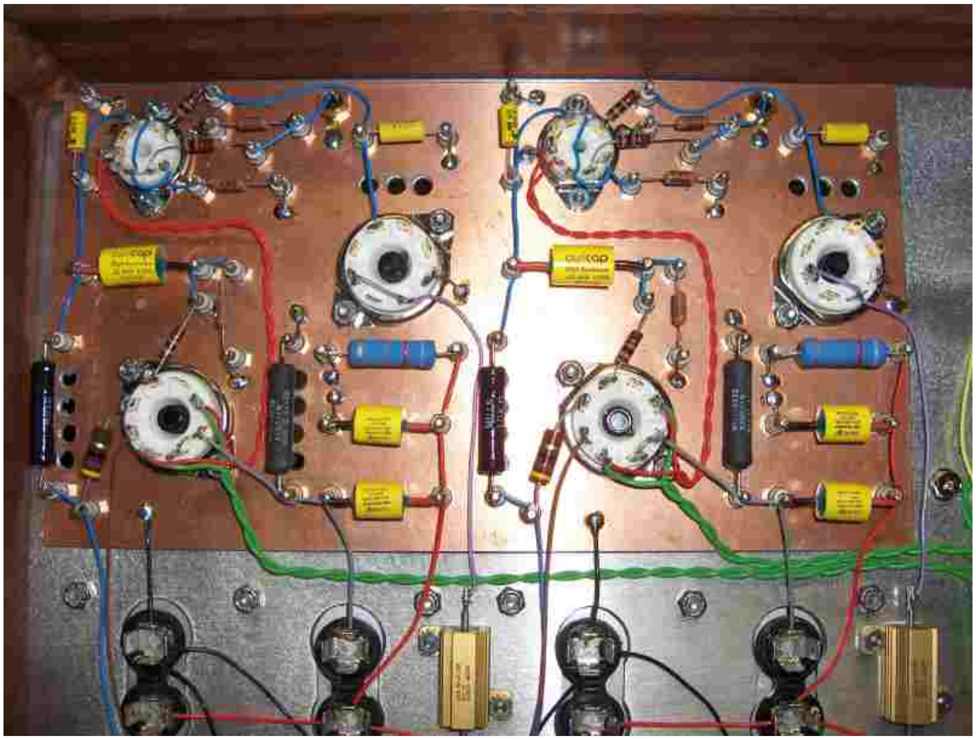
The drawings are pretty hard - OK, impossible - to read in the magazine. So I put together a PDF file of just the figures and drawings so you can read them (232k PDF file)

Mechanical drawing CAD files: AutoCAD 2000 DWG file (504kB) or R12 DXF file (964kB). This drawing has all of the details in it - turn on and off the different layers to get the info that you need.

To make use of these files, you'll need some kind of CAD software or CAD file viewer. Do a quick internet search for "DXF viewer" or something similar - there are free CAD programs out there that should work fine. With all layers on it's a little confusing!

If you don't want to mess with CAD... PDF view of the internal wiring (371kB PDF file) and a 1:1 close-up of the terminal board (140kB PDF file). Note that it's been brought to my attention that there is an error on the wiring diagram in the connections to the rectifier tubes - I'm one pin off on the connections. Please follow the schematic!

And, a parts list (.XLS file)



Build This Novice Four-Band Vertical

Basic Amateur Radio: Putting your first amateur station together can be an expensive proposition. One way to cut costs is to keep the antenna simple. Here's how I shaved the price and provided four-band operation.

By Marian Anderson,* WB1FSB

Is operation with one antenna acceptable if it covers the 80-, 40-, 15- and 10-meter bands? For a new Novice that's a reasonable approach, I decided. My backyard is smaller than that of most urban homes, so full-size dipole or inverted-V antennas were out of the question. I don't own a tower (yet!), so it seemed that a ground-mounted vertical antenna would be worth trying.

After reading the *ARRL Antenna Book,* I decided that a ground-mounted vertical antenna would be easiest to build. Some radial wires could be buried, and the metal fence which encloses the backyard could also be hooked up to enlarge the ground system. I preferred this type of antenna to one installed above ground, because radials of specific lengths for each of the four bands would have been needed for a roof-mounted, groundplane type of vertical. The buried wires for the ground-mounted antenna could be any convenient length, as long as the available space would permit. From what I have read about these antennas, I believe that reasonable performance can be had even if the ground radials aren't numerous and long, although generally the more you have, the better.

With the help of W1FB I purchased some used aluminum tubing that would telescope together and give me a 25-foot (7.62-meter) antenna. The wall thickness of the tubing is 0.058 inch (1.5 mm). Three 10-foot (3.1-m) sections are used. The largest diameter is 1 inch (25.4 mm). The center telescoping section has a diameter of 7/8 inch (22.2 mm) and the top piece of tubing has a 3/4-inch (19-mm) diameter. This material, plus hose clamps for holding the sections together, came to $8. An old ceramic rotary switch, a coaxial connector, a feed-through bushing, and a piece of Air Dux coil stock were acquired at a flea market for an additional $3. Two medium-size, ceramic standoff insulators were donated by W1FB. He said they cost him 50 cents each at a swap session. All that remained to collect was a weatherproof box for the loading coil, some 50-ohm coaxial cable and six U bolts. My OM, Bob, found some used 1-1/2-inch steel pipe (38 mm) which is 7 feet (2.13 m) long. It is used as a support for the vertical.

Constructing the Antenna

A lawn-edger tool was used to make slits in the lawn, out from the base of the antenna toward the edges of the backyard. The slits were cut to a depth of 2 inches (51 mm). A total of 10 radials were buried in the slits. Some are only 15 feet (4.57 m) in length, while others are 25 feet (7.62 m) long. The metal yard fence was bonded together as needed, using wire jumpers between the fence sections. A single buried wire joined the fence to the common ground point at the base of the antenna.

My OM drove the steel pipe into the ground to a depth of 4 feet (1.22 m), leaving 3 feet (0.91 m) above ground for attaching the vertical antenna and weather-proof box. Construction details are shown in Fig. 1.

Although a wooden box could have been used to house the loading coil, switch

*Technical Secretary, ARRL

and other hardware, I used an old electrical housing that my OM had in his junk box (Fig. 2). It was drilled and punched on the bottom surface to hold the feedthrough bushing, coaxial connector, switch and ground terminal for the radials.

W1FB designed the antenna, but he wasn't sure that an acceptable impedance match could be had on all four bands without a complex matching network. We decided to try his idea, so the installation was completed.

Adjusting the Vertical

I helped my OM install the antenna, then called W1FB for some assistance in tuning the system. He thought we could tune the vertical for 40 meters and make it work okay as a 3/4-wavelength vertical on 15 meters. For use on 80 meters it would be fairly short (63 feet or 19.20 m is the correct length for 3.7 MHz). With base loading it should offer adequate service out to a few hundred miles on 80 meters. Finally, it would operate as a 3/4-wavelength vertical on 10 meters.

We hooked a homemade SWR indicator in the coaxial line at the base of the vertical.[1] A small amount of transmitter power (5 W) was applied at 3725 kHz and the 80-meter switch lead was touched on the turns of the coil until minimum reflected power was indicated (Fig. 3). An SWR of 1:1 was obtained. The wire was then soldered in place on the coil. Next we fed power to the antenna on 7125 kHz and touched the 40-meter switch lead to the coil turns until an SWR of 1:1 was read. While using the same coil tap we fed power to the antenna on 21.1 MHz and checked the SWR. It was approximately 3:1. By moving the coil tap just one turn we were able to get an SWR of 1.5:1 on 15 meters. A recheck on 40 meters followed. The SWR for that band was less than 2:1 — not a bad compromise! The coil was bypassed entirely for operation on 10 meters: An SWR of 2:1 was indicated at 28,100 kHz. The length of the overall antenna for operation on 28,100 kHz should be 25 feet or 7.62 m (3/4-wavelength radiator). However, the switch leads inside the coil housing add to the antenna length. If an SWR of less than 2:1 is desired, break the 10-meter switch lead and insert a 100-pF air variable capacitor. The unwanted reactance can be tuned out by this means and a low SWR will result.

Opening and closing the cover of the metal box had only a minor effect on the SWR. We were ready at last for an on-the-

[1]DeMaw, "A QRP Man's RF Power Meter," *QST*, June, 1973.

Fig. 1 — Dimensional drawing of the four-band Novice antenna. The top ends of the two lower tubing sections are slit four times each by means of a hack saw. This permits a tight joint when the hose clamp is compressed. The vertical is attached to one metal plate with U bolts. The large standoff insulators with metal feet connect this plate to a pair of small ones. The latter are attached to the steel support pipe by means of two U bolts. The metal box is also affixed to the steel pipe with two U bolts. The band switch is a single-pole three-position ceramic wafer type. L1 can be a 5-inch (127-mm) length of B & W 3029 Miniductor, 2-1/2 inches (64 mm) in diameter, 6 turns per inch of no. 12 wire. See text for alternative mounting methods.

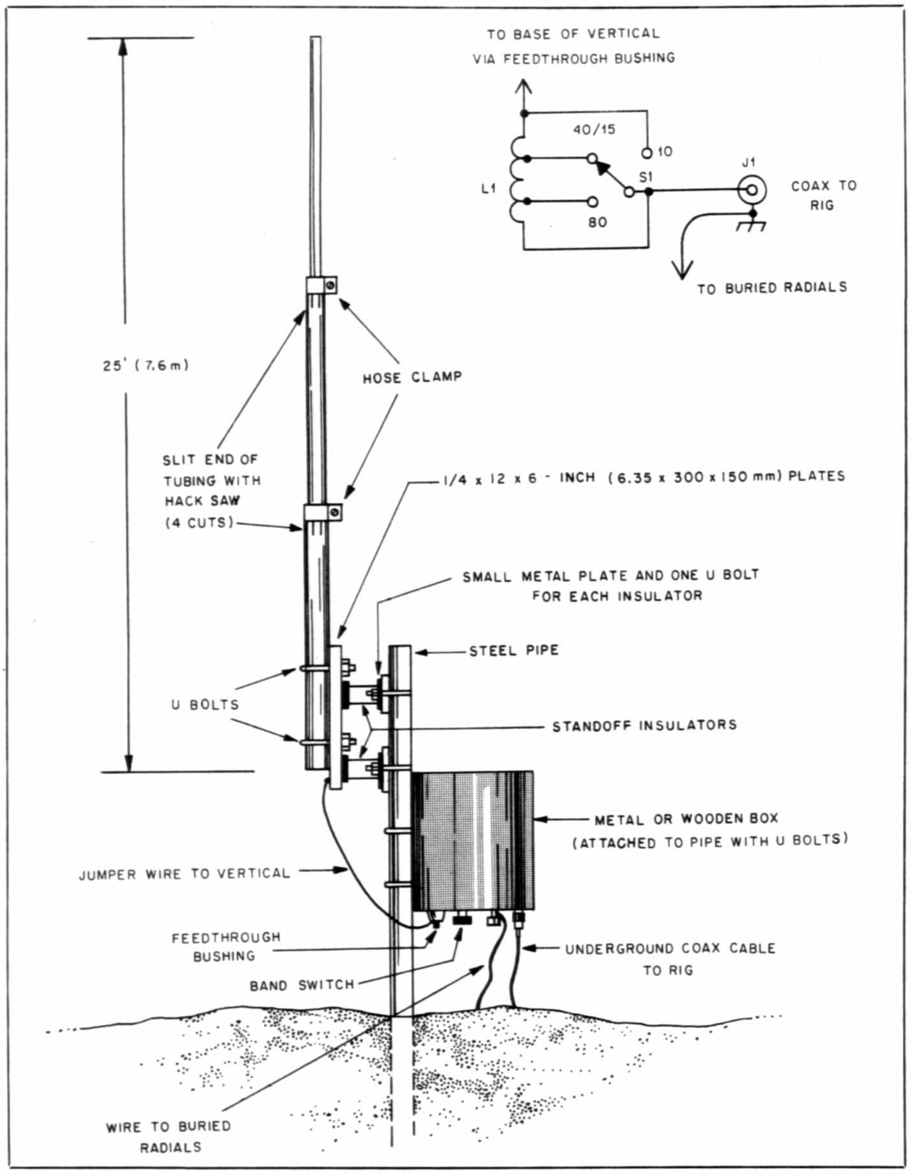
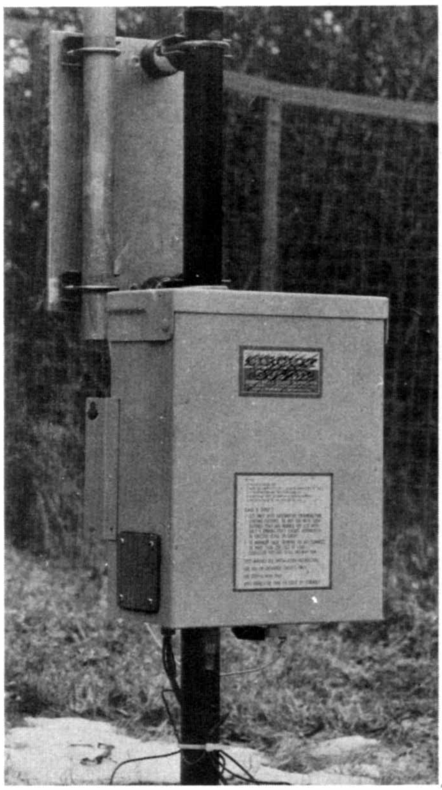


Fig. 2 — Closeup view of the base of the vertical. The aluminum tubing is affixed to a metal plate. The latter is attached to the iron support pipe by means of two surplus standoff insulators. Small aluminum plates are attached to the ends of the insulators to permit them to be fastened to the iron pipe by means of U bolts. The radial wires are connected to the bottom of the coil-housing box.



air test of the system. Fig. 4 shows the interior of the coil and switch housing.

Results

Good signal reports have been received on all bands. The first QSO on 40 meters netted an RST 599 report from North Carolina and many similar reports followed on 80, 15 and 10 meters. I feel that my WAS award is not too far away now that this antenna is in operation.

An Alternative

There are many ways you can duplicate this design using substitute materials. For example, electrical conduit with couplers between the sections should be satisfactory in place of the aluminum tubing. The entire structure could be made from 2 × 4 (50 × 100 mm) lumber. If that is done, the radiator could even be a 25-foot (7.62 m) piece of no. 10 wire, supported on the side of the wood with standoff insulators.

Instead of the mounting method shown in Fig. 1, the vertical pipe could probably be inserted into a 2-foot (0.61-m) length of PVC tubing, then clamped to the mounting plate. This would eliminate the need for the two standoff insulators. Better still, four or five wraps of Teflon sheeting (10 mil or 0.25 mm thickness) could be placed over the bottom end of the vertical before clamping it in place on the mounting plate. Teflon can be purchased at most plastic-supply houses.

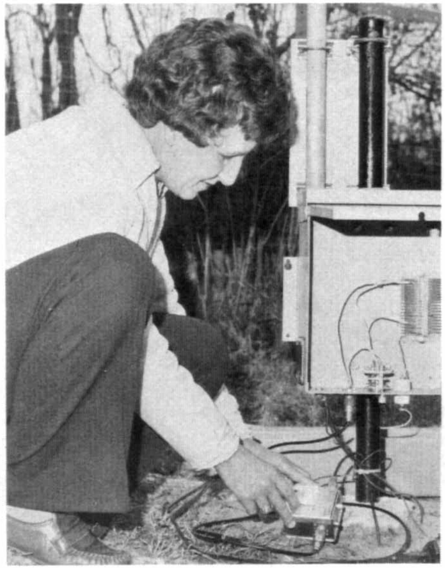


Fig. 3 — The author checks the SWR of the antenna during final adjustment of the system.

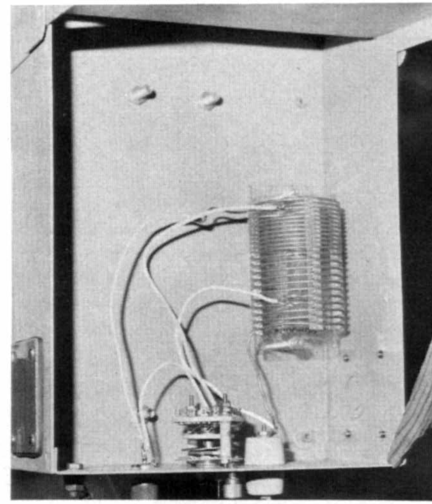


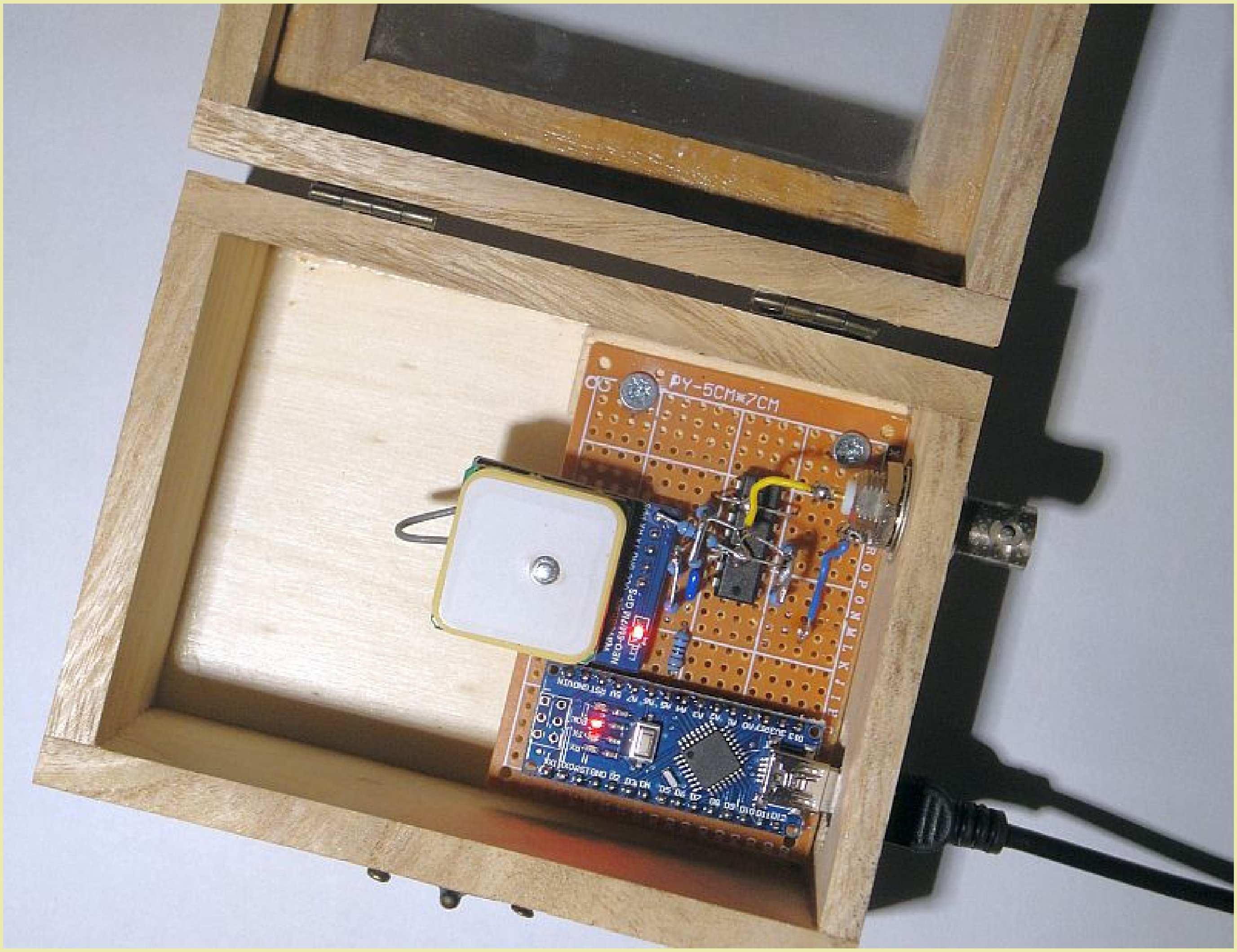
Fig. 4 — Interior view of the coil housing showing the switch, feedthrough bushing, coaxial connector, and ground post for the radials. The coil shown is a piece of Air Dux stock with a tapered pitch. It was obtained at a flea market.

I hope this idea is useful to other Novices who are trying to keep the budget within reasonable limits. I like the way my antenna is working. Others should have good luck with this antenna also. Oh, by the way, the ground radials are made from various scraps of wire. The size isn't important, and they can be insulated or bare. I have quite an assortment of wire types buried in my lawn!

SIMPLE 10 MHZ GPS FREQUENCY STANDARD AND RF GENERATOR

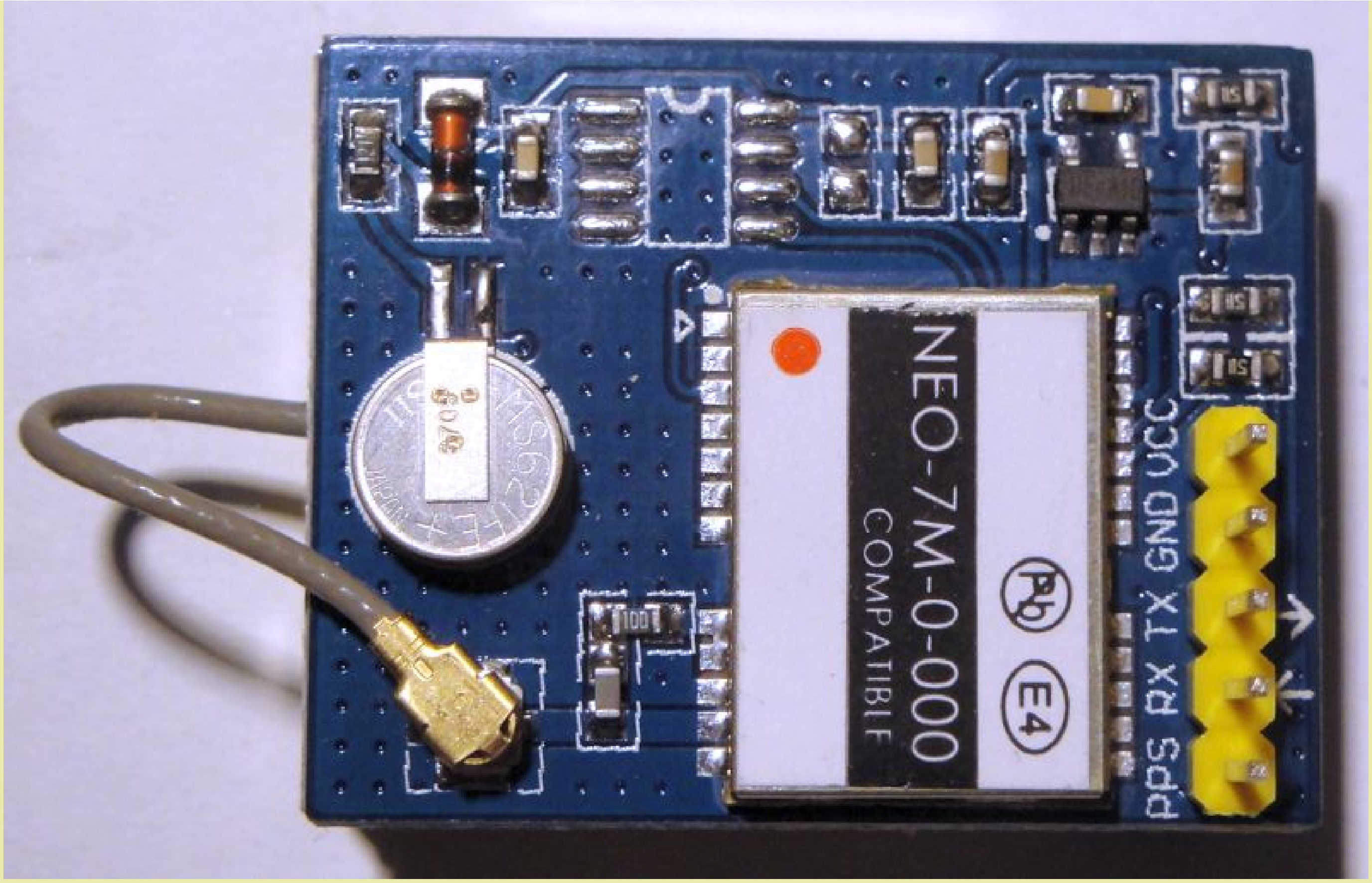
(2017)

KLIK HIER VOOR DE NEDERLANDSE VERSIE



The simple GPS frequency standard and RF generator.

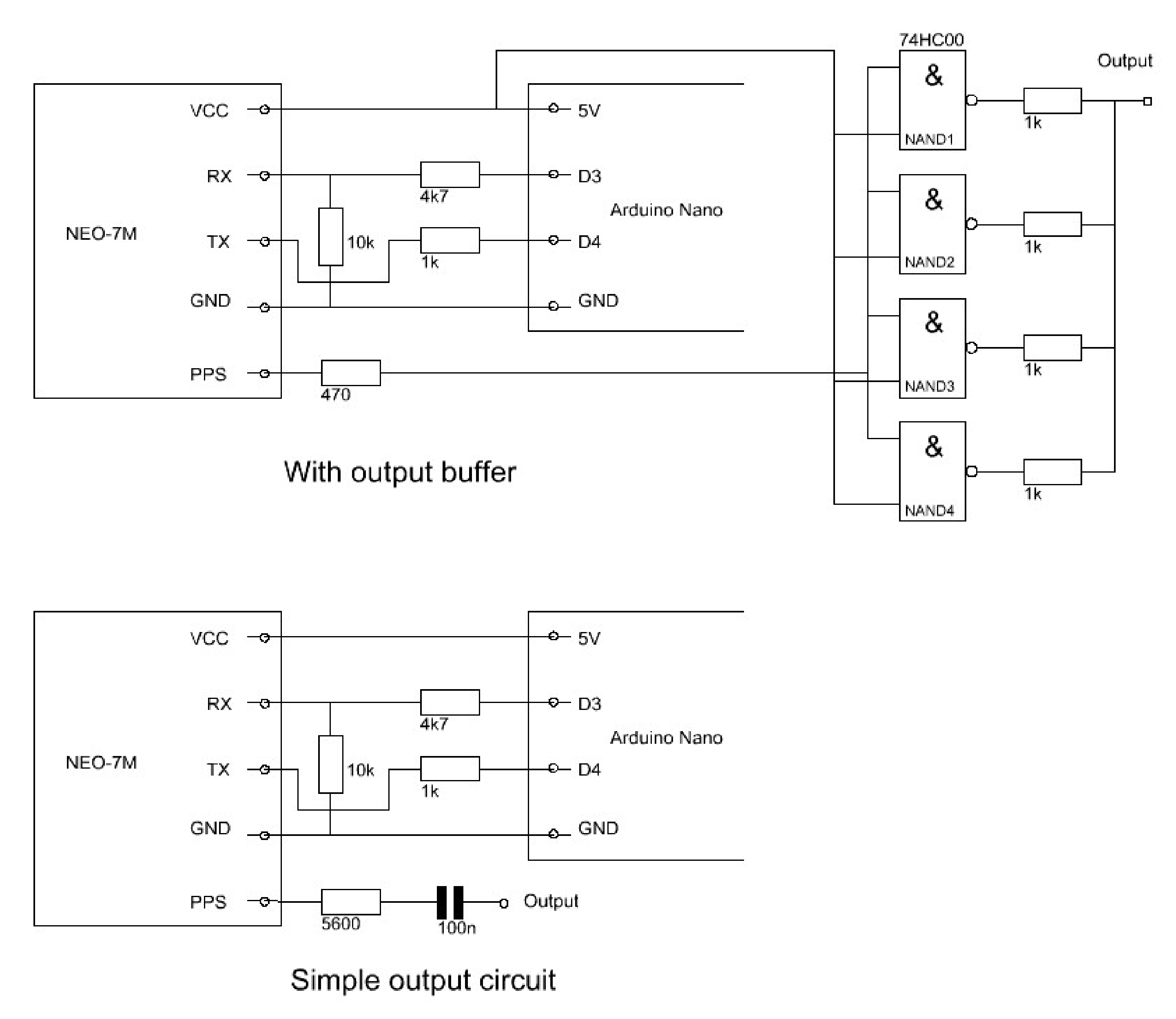
Simple GPS frequency standard and RF generator
My first frequency standard is built up around a GPS receiver module, model NEO-6M, type NEO-6M-0-001 of the company "u-blox AG". The disadvantage is however that it can generate a maximum reference frequency of 1 kHz. But this new GPS module model NEO-7M, type NEO-7M-0-000 can generate reference frequencies upto minimal 10 MHz with a resolution of 1 Hz! For example 10139991 Hz! And it goes even higher than 10 MHz at the expense of some extra jitter. Great, a real RF generator that can be adjusted in steps of 1 Hz and with an accuracy of minimal 2e-8! perfectly suited for all kinds of applications. Unfortunately, the signal is not clean enough to use it as a VFO for a transmitter or a receiver.



The GPS module model NEO-7M, type NEO-7M-0-000

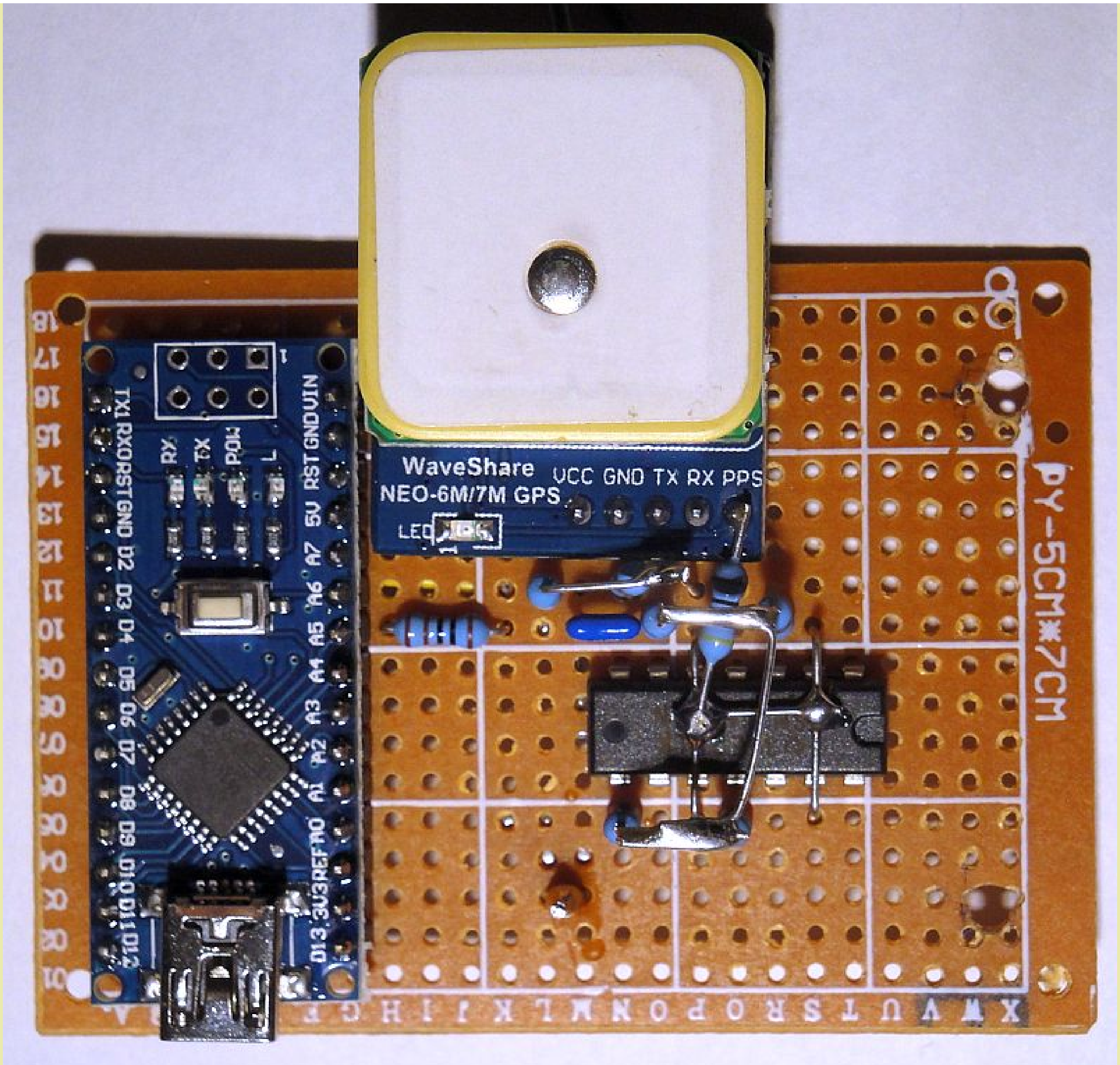
Hardware

The module is built around a GPS receiver module, model NEO-7M, type NEO-7M-0-000 of the company "u-blox AG".
Ayoma Gayan Wijethunga had described in his blog how the GPS module can be connected to the Arduino Nano and how you can communicate then with your PC with the GPS module. A very simple program in the Arduino sends the commands from the PC to the GPS module and from the GPS module to the PC. And you can see them with the in the IDE integrated Arduino Serial Monitor.
And also the programming of the time pulse is very simple and will be discussed later.



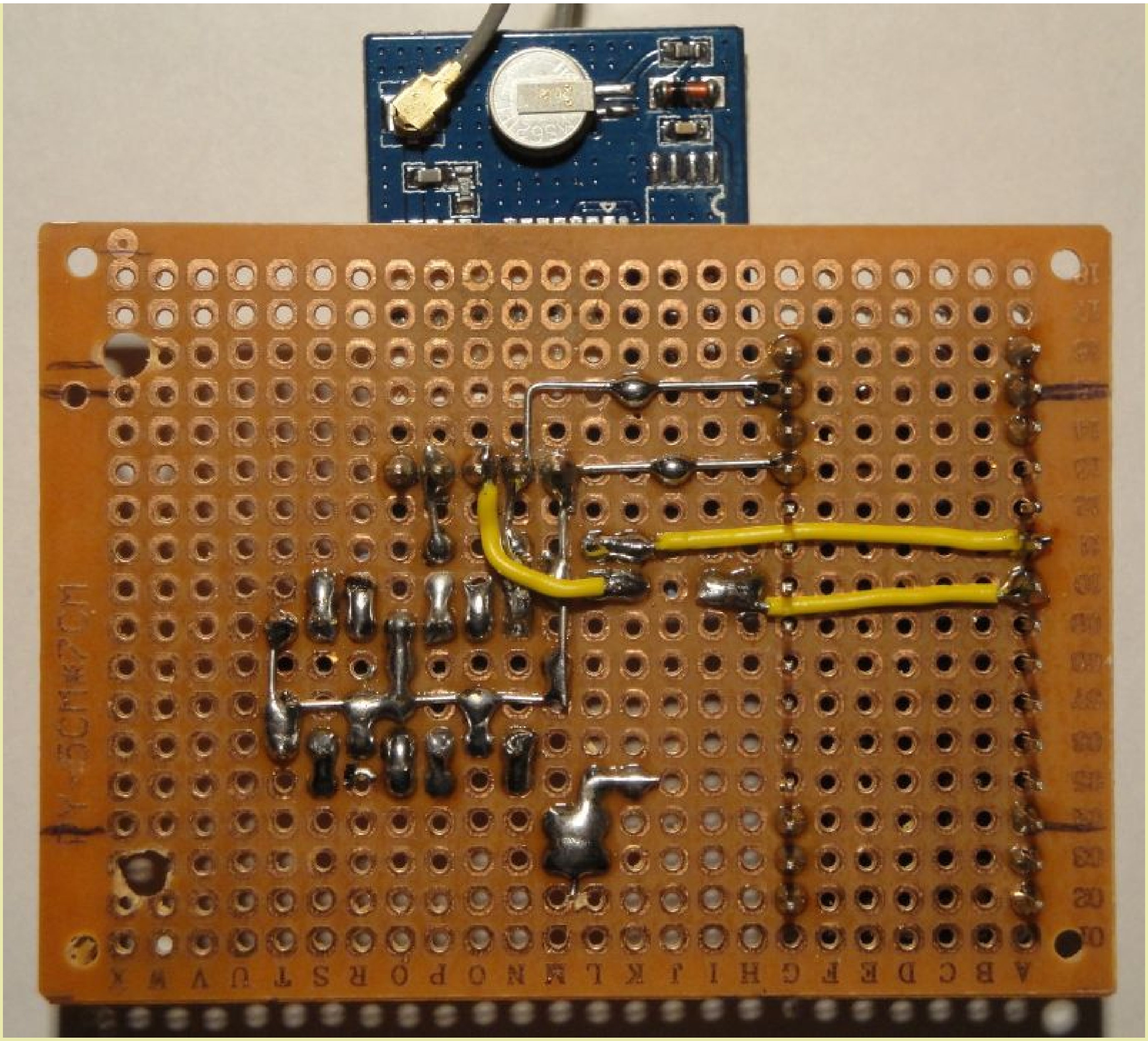
Diagram

The GPS receiver works with 3.3 volt levels and therefore there is an attenuator network with a resistor of 4,7k ohm and 10k ohms inserted between the 5 volt data output of the Arduino Nano and the RX input of the GSM module. The 3.3 volt TX output of the GSM module is just enough for the input of the Arduino Nano. I have added a 1k resistor between as security. When something goes wrong at the Arduino Nano side, it is almost sure that the GSM module will survive.



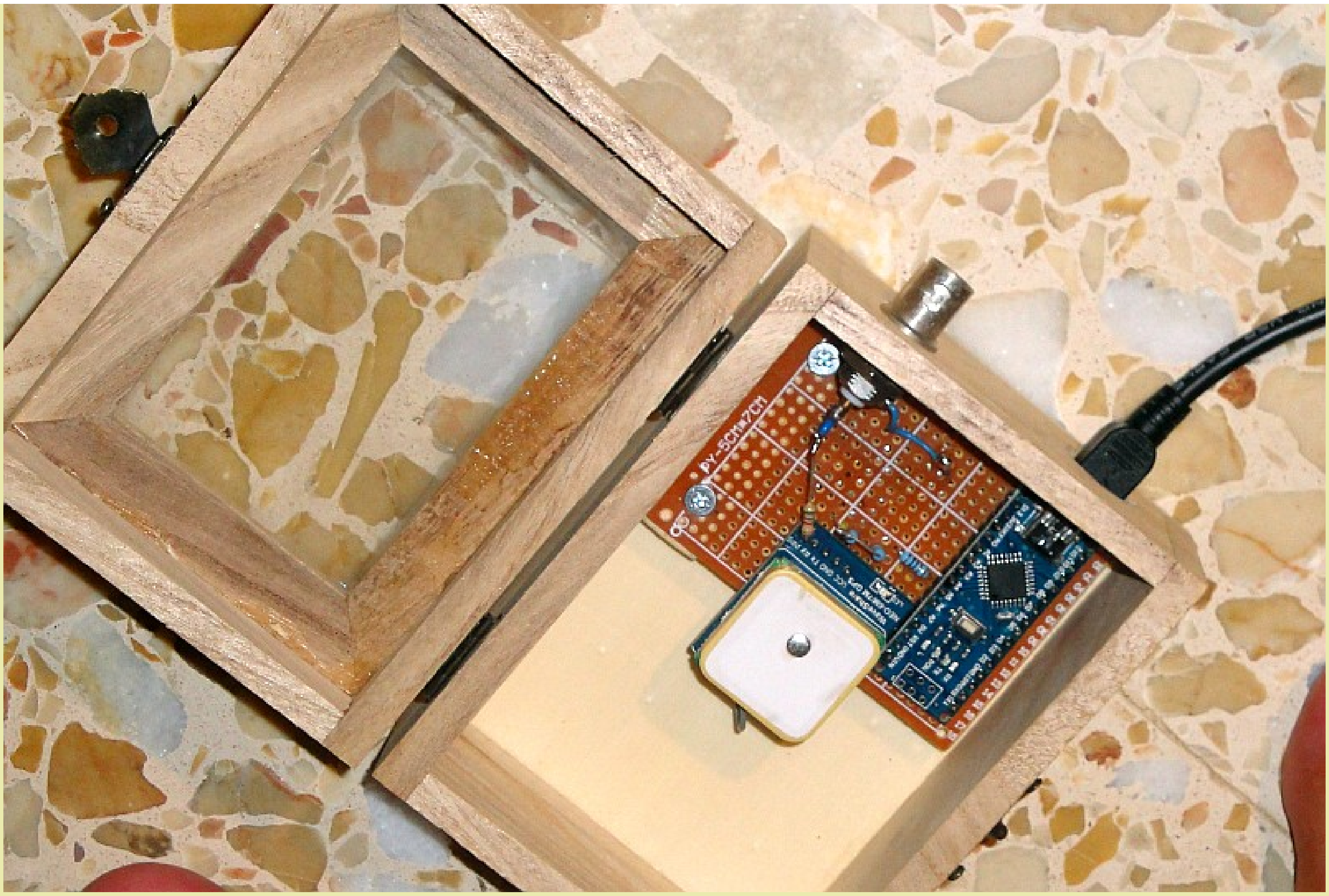
Print, topside

Of course, we can not connect the time pulse output (PPS pin of the GSM module) directly to all kinds of applications. I made a buffer with a 74HC00, in the future I want to use it to make AM modulation by connecting the 4 inputs of the NAND's not with +5 volt but with a 1 kHz. Of course you can also use a 74HC04 as a buffer. A 74HCT00 or 74HCT04 is also usable.



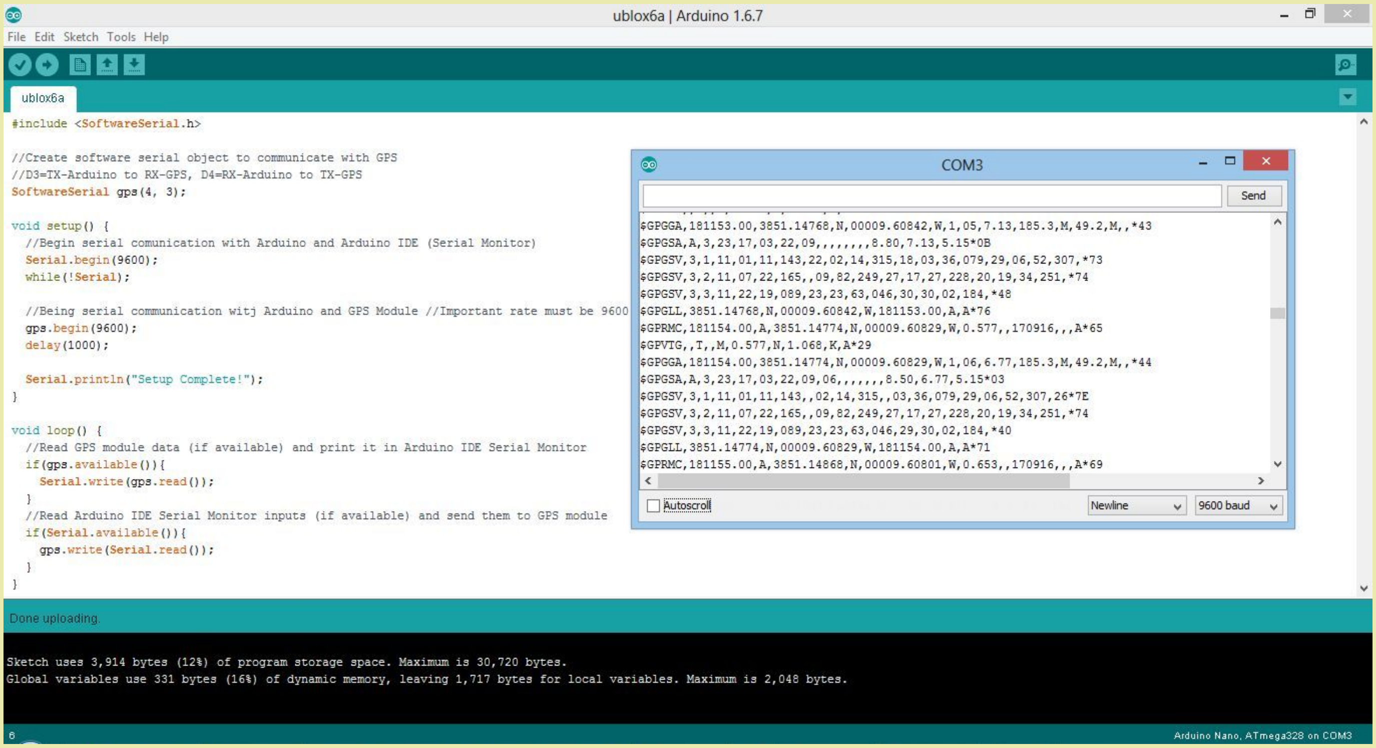
Print, bottom side

The whole is built in a wooden box for tea bags with a window in the lid, so that you can see the leds light up. The Arduino Nano, the 74HC00 and GPS module ares mounted on a piece of pertinax. The solder pins are made of cut-off wires. Bend them into a U-shape, insert them through two holes and twist the ends together.



New version with simple output circuit

New version with simple output circuit
After a while in use, I removed the 74HC00 buffer and installed a simpler output circuit. Just a series circuit of a 5600 ohm resistor and a 100 nF capacitor. The buffer gave too much output signal and the strong harmonics even disturbed the GPS module. And protection against electrostatic discharges is not necessary when you walk barefoot on a stone floor!



The developement environment (IDE or Integrated Developement Environment) of the Arduino.
Also the small Serial Monitor screen is visible with the data of the GPS module.

Software for Arduino Nano

Programming a micro controller has never been so easy, even a layman can learn it in a few minutes! You can find it at https://www.arduino.cc/ under downloads. And there is much more information about the various Arduino versions. I use the Arduino Nano.

Download and install the IDE. Connect the Arduino Nano with your USB port on your laptop and with "Tools - Port" you can select the correct COM port. When it works, you have the correct COM port.

With "File - Open..." you can open a program, that is a file with the extension ".ino". With the first V on the toolbar, you can check if a program has errors. With the second round with an arrow you can compile the program, uploaded it and then you are ready!

A program consists of two parts. The "void setup ()" part contains the configuration, for example which ports are configured as input or output. The second part "void loop ()" contains the program. More information can be found on the above mentioned website of Arduino.

Type the following simple little program "ublox6a.ino" over and upload it by pressing the second round with arrow. Then choose "Tools - Serial Monitor" (not Serial Plotter!) And you will see the data from the GPS module appear on the monitor screen.

ublox6a

```
#include <SoftwareSerial.h>

//Create software serial object to communicate with GPS
//D3=TX-Arduino to RX-GPS, D4=RX-Arduino to TX-GPS
SoftwareSerial gps(4, 3);

void setup() {
  //Begin serial comunication with Arduino and Arduino IDE (Serial Monitor)
  Serial.begin(9600);
  while(!Serial);

  //Being serial communication witj Arduino and GPS Module //Important rate must be 9600
  gps.begin(9600);
  delay(1000);

  Serial.println("Setup Complete!");
}

void loop() {
  //Read GPS module data (if available) and print it in Arduino IDE Serial Monitor
  if(gps.available()){
    Serial.write(gps.read());
  }
  //Read Arduino IDE Serial Monitor inputs (if available) and send them to GPS module
  if(Serial.available()){
    gps.write(Serial.read());
  }
}
```

The simple program "ublox6a.ino" for the Arduino Nano.

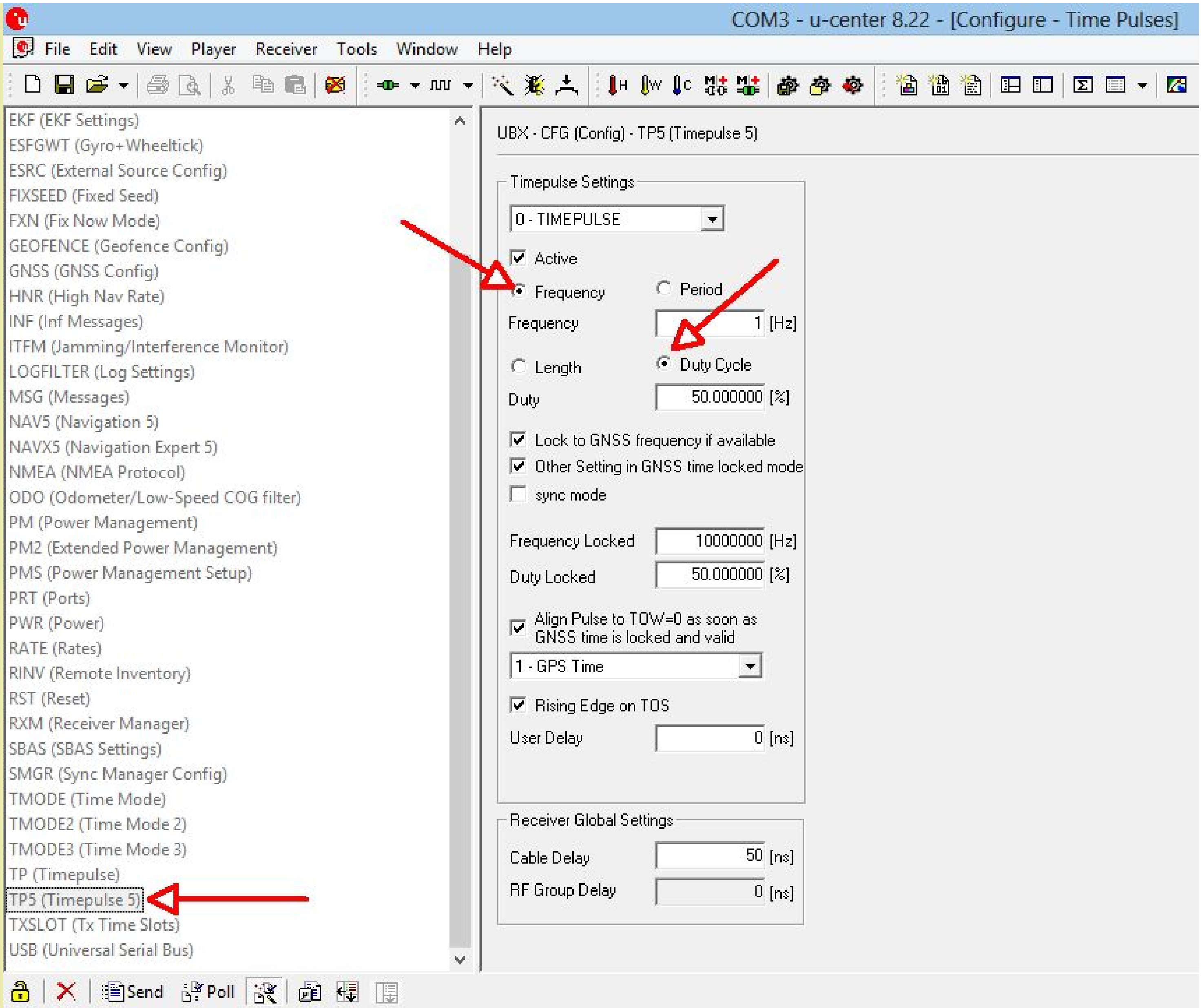
CLICK HERE TO DOWNLOAD THE PROGRAM FOR THE ARDUINO

Software for GPS module

We have already programmed the Arduino Nano and connected it to the USB port of the computer. Shut down the IDE of Arduino Nano. The Arduino Nano is now working as an USB-UART device.

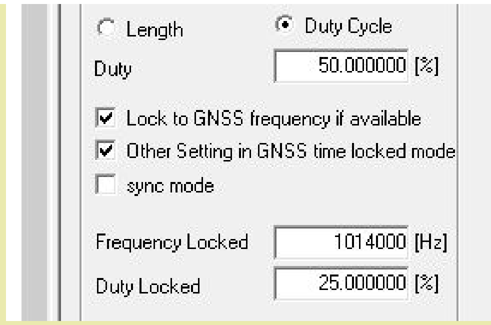
We use the "u-center software" which can be downloaded from the manufacturer's website: https://www.u-blox.com/en/product/u-center-windows. With the first choice on the toolbar, you can select the correct COM port. If you do that correctly, it will work.

With the program you can see lots of things like the strength of the signal of the satellites, your position on Google Maps and what we want to use, programming time pulse!



De "u-center software", the part with which we can configure the frequency.

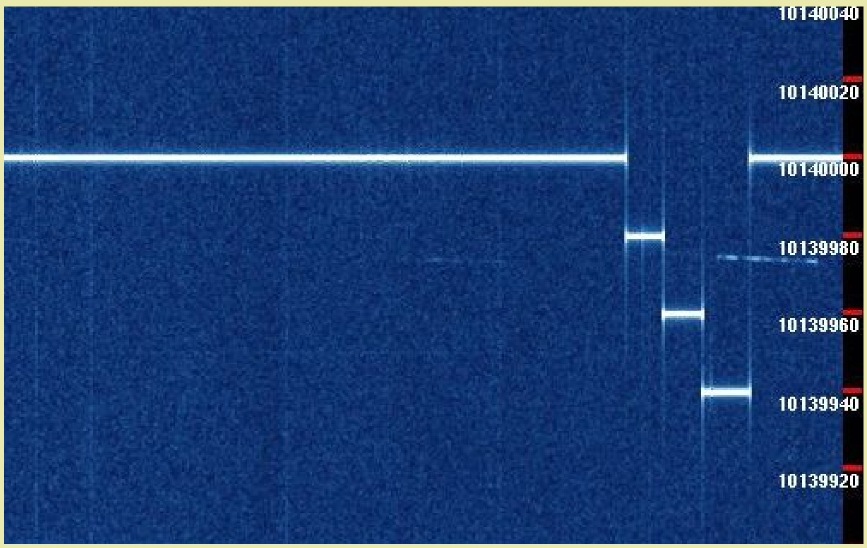
For the NEO-6M module we did use "TP (Timepulse)" to program the reference frequency. But for the NEO-7M that does not work and we have to use "TP5 (Timepulse)". Activate "Frequency" en "Duty Cycle". You have to program two frequencies, one for when there is no fix. I programmed it for 1 Hz so that the led blinks if there is no fix. You reference frequency has to be programmed in the part "Frequency Locked". This can be any frequency you want till at least upto 10 MHz. My module did work till 16 MHz, but then you will have some jitter.
You can save the setting. This has to be done in the choices "BBR-0", that is the backup memory and in "3-I2C-EEPROM". Unfortunately, my module does not have a EEPROM and I have to reprogram it often when the backup battery is discharged.
Mark VK6WV had the following remark:
"When I save the configuration as your article suggested it did not save. After reading and re-reading the user guide I went to GNSS configuration under "Tools". I read the GNSS to a file after making sure TP5 had been set. Then I saved this same file back to the device with the "Store Configuration into BBR/Flash". This worked."



Setting to calibrate the QRSS receiver on 10140 kHz.
The 10th harmonic of the signal is used.

Use

Indoors, the GPS receiver has sometimes some difficulty to find a FIX. I use a power pack as is used for smartphones when playing Pokemon Go to feed the frequency standard and then go outside. When it has found the FIX, it will continue to work well when indoors.
The module in the wooden box radiates enough power to calibrate my receiver. The signal on 10140 kHz is even too strong, I use the 10th harmonic of 1014 kHz.
The used module is an outdated model, there are newer ones. See https://www.u-blox.com/en/position-time.



A perfect signal to calibrate the QRSS receiver on 10140 kHz.

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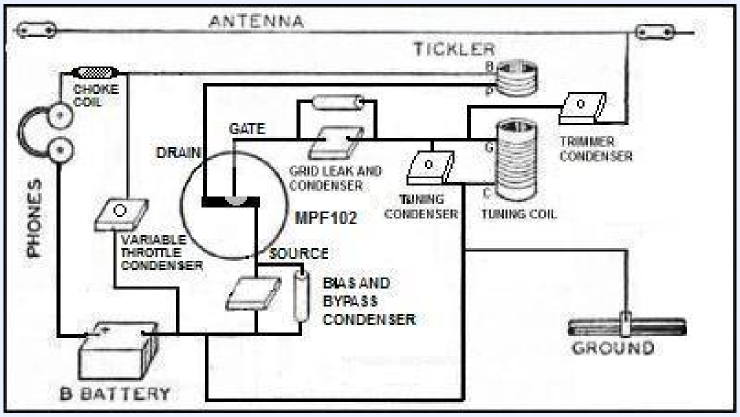


AN ARMSTRONG "CRYSTAL" RADIO
using the silicon crystal inside the FET as the crystal

A project from the book "The Old Geezer Electrician"
by John Fuhring

Please note that this is a STORY
or, if you prefer, an E-book that you can read for free. This story contains opinions, historical data and biographical material not usually found in articles that are strictly technical, but it also contains a lot of detailed building instructions and suggestions.

This is a long story involving a lot of reading, but you don't have to read everything unless you want to. If you are only interested in the technical and/or building aspects of this story, I invite you to skip those parts you are not interested in. When you are done with the story or with looking things over, I ask you to sign my guestbook or send me an E-mail and tell me if you liked the story or not.

If you are a young person, I think building this radio and writing up how it works would make an ideal Science Fair project. This little project is very easy to build using ordinary tools and you won't need anything more than the ordinary skills and craftsmanship that kids like you have. You can even build this radio without help or support from adults. I also highly recommend it to those who want something simple to build, but also want something that is far and away better than any diode crystal radio.

Foreword
to the yet to be published book
The Old Geezer Electrician

Back in the late 50s and early 60s my nascent career in electronics was encouraged by the many wonderful construction articles in Popular Electronics, Popular mechanics and Popular Science magazines, but it was a 1940 edition of an old book I found in the City Library that really got me going. That old book was written by Alfred Morgan and was titled "The Boy Electrician." Mr. Morgan and his "Boy Electrician" book went back a long way, with the first edition printed in 1913. By the time I got this book, around 1958, the technology in it was already 20 to 50 years old. Still, the book contained a lot of good, solid basic stuff and several wonderful projects that a kid could build and learn while doing.

One project that really caught my fancy was the Armstrong Regenerative radio. I had built and experimented

with crystal radios before, but I was ready to move up to something better. I was very lucky because the 1H4 tube the project required was still available, otherwise the project might have ended right there. Of course, I did not have the skill and tools to build the radio as it was described. The specified tube socket and the exact coil form were both unavailable, but half the fun of building this radio came from the opportunity to improvise (like using a toilet roll for a coil form) and to invent construction techniques that matched my building skills.

My regenerative radio from 1958
There is a link to my regenerative radio here and at the end of this story.
This radio is functionally identical to Armstrong's 1911 radio except
that my 1H4GT triode is a much better tube than his Audion triode was.
Both this and Armstrong's radio need an 'A' battery and a 'B' battery.

The (in)famous 2012 Geezerola Radio.
(Geezerola is just a silly name I chose, you can call your radio anything you want)
This little radio is functionally identical to Armstrong's 1911 and my 1958 triode tube radios except,
unlike triode vacuum tubes, the crystal in my triode will pass electrons without heating the cathode.
Without the need to heat a cathode, my radio needs only a single (9 volt) battery.

Well, a lot of time has passed since I built the Boy Electrician radio (yeah, like 55 years), but I can truthfully say that the little project did exactly what Mr. Morgan intended it to do. It took a young boy, me, and it inspired him to go on and learn more about electricity and eventually make his living working with electricity. I was that "Boy Electrician" and now I am this "Old Geezer Electrician." In my status as "Electrician Emeritus" I plan (in a very small way) to emulate Alfred Morgan and present a little regenerative AM radio for the education and inspiration of all the aspiring Boy Electricians, Girl Electricians, Adult Electricians and even my fellow Old Geezer Electricians. What is more, I am presenting this as a building project using the same simple skills and techniques that just about everybody possesses and that I used to build my 1958 radio.

So, here's the first chapter of my proposed book "The Old Geezer Electrician" and I hope you like it.

Introduction

A while back I got working one of the best crystal radios that was ever offered to the buying public, a Heathkit CR1 receiver. As I experimented with it, I was very impressed with its performance both in terms of its excellent selectivity and, for a crystal radio, its sensitivity. On those evenings when the "skip" is in, I can hear stations over 200 miles away.

After having fun with my CR1 and impressing myself with its performance, I thought I'd do a performance comparison between it and my 1958 "Boy Electrician" regenerative radio. Even as far back as 1958 I knew that my Armstrong tube radio was far superior to any of my simple crystal radios, but now I had this excellent CR1 crystal radio at my disposal so that I could now compare a good crystal radio to a simple regenerative radio.

As good as the Heathkit CR1 radio is, it was completely and totally outclassed by my old Armstrong radio. Once again I was impressed by the old regenerative radio's selectivity -- about as selective as a superheterodyne -- and I was impressed with how well I could pull out the weak, far away stations and hear them clearly even with a short antenna. There was no comparison really. The CR1 crystal radio is fine for listening to strong local stations if they aren't too close to each other and if you have a huge long antenna, but it is greatly inferior to my old regenerative radio in every respect.

The difference in performance between a good crystal radio and even a simple regenerative radio is so profound, it set me to wondering why anybody today would bother building a crystal radio especially when you consider that such a radio is just as cheap and easy to build as the simplest crystal radios.

So, if a simple FET regenerative radio is so superior to any crystal radio, what can account for the fact that crystal radios never went totally extinct and people are still building them? Well, there is a great appeal in building and using a radio that is so primitive and so simple that it needs no "high tech" components or even a battery. I mean, a crystal radio can be made from materials that have been available to people since before the Bronze Age. All you need is copper wire (available since 5,000 BC) and a rock crystal (available since 4.5 billion BC). Add that to the fact that the energy to produce sound in the headphone is "free" and comes from the radio station, building and operating crystal radios are still fun. A big waste of time (in my opinion), but still fun.

Simple homemade radios go high tech

The better and most useful crystal radios that people build today are not much like the crystal radios of the past. Today's crystal radios are pretty "high tech" and are built with modern components that our ancestors didn't have. The thought has occurred to me, if today's crystal radios are so high tech, why not go a little further and replace the crystal diode detector with a Field Effect Transistor (an FET) which contains a tiny piece of silicon crystal? Both the crystal diode and the FET rely on a crystal of geranium or silicon to work, so why not call the FET radio an Armstrong "Crystal" Radio? Yes, I know, the crystal radio purists will be shocked to hear somebody call an amplified radio with a battery a *crystal radio*, but I'm going to call my little radio one anyway.

Is my Armstrong "Crystal" radio really so much better than anybody else's crystal radio? Frankly, my little radio is as cheap, easy and simple to construct as the most basic crystal radio, while at the same time it is vastly more sensitive and is vastly more selective than even the most elaborate high performance crystal radio. These are not just words, I invite anybody to compare the performance of their best and most complex crystal radio with my simple Armstrong "crystal" radio. Simply by substituting a common and inexpensive Field Effect Transistor (an MPF102) for the 1N34A diode, adding a tiny battery and changing a few circuit elements around, I have built a little radio that will run rings around anybody's crystal radio.

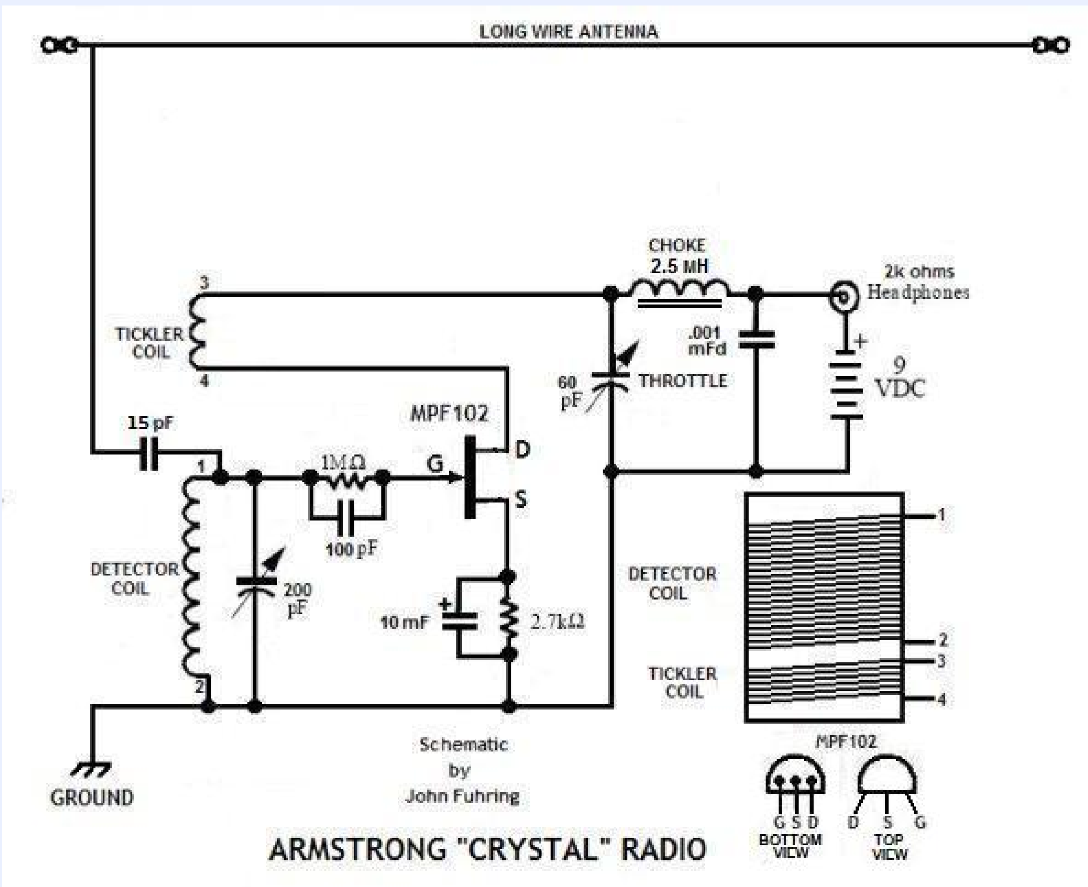
So, let's compare my crystal radio's parts list with my Armstrong crystal radio's parts list.

My Armstrong "Crystal" Radio	My traditional Crystal Radio Kit
dozens of turns of ordinary (30 ga) wire	dozens of turns of Litz Wire
a few turns of ordinary (30 ga) wire	dozens of turns of Litz Wire
coil form using a toilet roll	2 ferrite toroid coil forms
variable tuning capacitor 200 PF (60+140)	variable tuning capacitor 360 PF
variable tuning capacitor 60 PF (140 not	variable tuning capacitor 360 PF

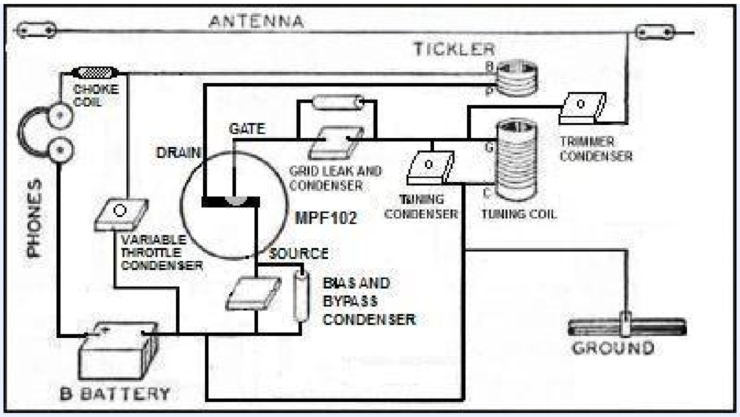
used)	
MPF 102 Field effect transistor	1N34A point contact diode
1,000 pF, 100 pF & 10 pF ceramic caps	caps not used
1 ea. 1 M ohm & 2.7 K ohm resistors	2 ea. 22 ohm & 1 ea. 24 K ohm resistors
no switch used	selectivity switch
choke coil 2.5 millihenry	choke coil not used
battery 9V	battery not used

As you can see, both radios use similar parts and the difference in cost between the two radios only amounts to a couple of dollars either way. My little radio is as simple as the most basic (very poor performing) crystal radios and it is as cheap to build, but (and this is an important 'but') it vastly outperforms even the most elaborate crystal radios. Because of all this, I think that the choice is obvious, the Old Geezer Electrician radio is what you should build.

Building the radio

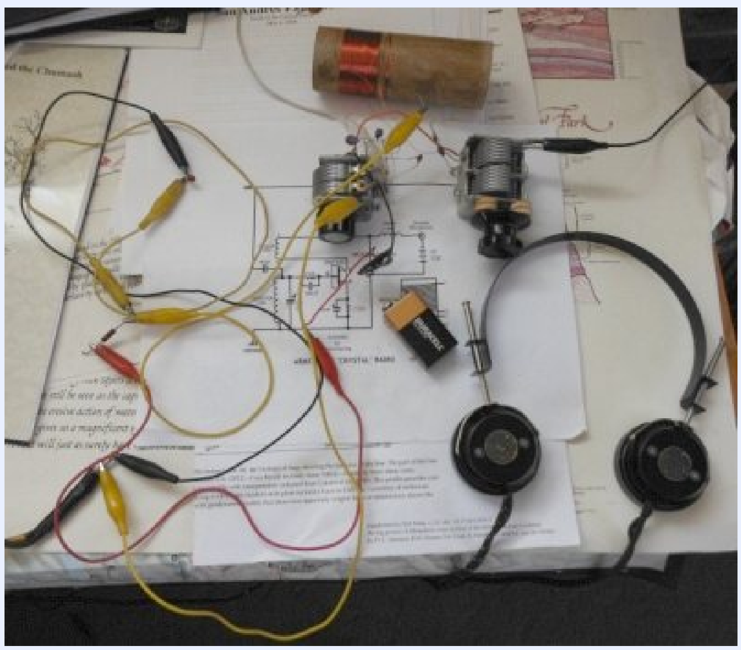


Armstrong "crystal" radio schematic diagram.



How the book "The Boy Electrician" would have shown this schematic.
Of course, there were no FETs back in those days.

Before finalizing the schematic and writing up a story for my website, I needed to prototype the radio, get it working and see if it would really work and be worth building



Kludging together the components to test the design.
The photo above shows how I tack-soldered and jumpered the FET, coils, variable condensers and various other parts together to test just how well such a simple radio performs. In all truth, I was really surprised, I mean, really, really surprised how sensitive and selective this kludged up mess turned out to be.

The prototype radio only took me a few minutes to tack together. I used a toilet roll doped with liquid plastic as my coil form. The hardest part was winding the tuning coil with No. 30 wire, but even that only took a few minutes. I spent the next few days experimenting with and enjoying using this little radio. The more I played with it, the more I knew that it would a most excellent little project for a "Boy Electrician" or a "Girl Electrician" or a "Adult Electrician" or even a "Old Geezer Electrician."

By the way, the current draw from the 9 volt battery is a whopping 0.9 milliamps. Yes, the radio draws all of 0.0009 amps and at 9 volts, it burns 0.008 watts (8 milliwatts) of power. I wonder how many months a 9 volt battery would last at that rate if I left the radio on day and night? Fortunately for the battery, when I remove the headphones from the jack, it cuts the power and no current flows from the battery. Isn't that a cool way to avoid having an on/off switch? Due to the miracle of the human ear and the extreme efficiency of my magnetic earphones, this tiny wattage is so loud I have to shove the earphones forward off of my ears when listening to a

local station.

The "MYSTERY OF THE GATE TICKLER" circuit.

Lately (July 2014) a gentleman asked my why I bothered to include the "gate tickler" circuit since an FET's gate does not collect electrons and they don't self biases as triode tubes do. Of course they don't, that's why I included the 2.7 (or so)K resistor and 10 uF capacitor in the source circuit, but in this case, the gate tickler circuit is not for biasing, but to improve the performance.

At first, I too assumed that the gate tickler was not necessary and I built my prototype without one. My prototype failed to perform as well as my 1958 tube type regen and so I searched for ways to improve it. When I added the gate tickler to the prototype (on a sort of a whim), I experienced a very noticeable improvement in the overall performance of the radio, including improved sensitivity, easier tuning and easier throttle control. With the gate tickler circuit in there, the performance of the FET radio is fully equivalent to the performance of the triode tube radio. Please don't ask me why because I'm sure the answer is way beyond my level of theoretical knowledge, but gee does it work and you can't argue with success.

Getting down to brass tacks

You know, I've always wanted to build another simple, low cost, high performance radio using brass nails driven in a wooden board for mounting the parts, but the new radio would feature a simple and cheap Field Effect Transistor (FET) instead of the big, rare and fragile triode tube and its big battery set. I got the idea for mounting parts on a wooden board with screws and nails 55 years ago when I built my Boy Electrician radio and I always thought I'd like to do it again. In fact, when I was an idealistic young man, I thought this ultra simple and ultra cheap way of building a radio might be an ideal project for really poverty stricken places in India and Africa so that kids there could learn about electronics and even very poor people could listen to the radio. Well, I soon realized that in those kinds of places, simply buying those very inexpensive factory made transistor radios was the best way for them to go and the kids had no access to transistors, resistors, capacitors or soldering irons.

Regardless of all that and after all these years, I've finally done it, I built a simple transistor regenerative radio based on this ultra easy and ultra cheap construction technique and you know, it is still a fun, quick, cheap and easy way to build something that really works and works surprisingly well.

As I did with my first regenerative radio, I used a paper toilet roll as my coil form and I simply glued it to the wooden chassis board. Shortly I will describe doping the paper tube and how to wind the tuning and tickler coils on the toilet roll.

Besides an ultra-cheap radio with outstanding performance, my main goal was to design something simple enough so that anybody could build it with just ordinary tools, simple skills and just ordinary craftsmanship. To accomplish this, I went back to the late 1950's and repeated the original building techniques I used to build my "Boy Electrician" radio. Of course, there is no reason why you can't build it to look nicer if you want to, especially if you have the tools and the skills -- and the patience for that sort of thing. Just remember this, "Hansom is as hansom does" and as crude as it looks, this little radio performs quite handsomely and will perform every bit as well as the better looking projects.

If you are looking to build a nicer version of this radio, I recommend building the Geezerola Senior. There is a link to that project at the end of this story. The Geezerola Senior is only slightly more difficult to build, but it sure looks nice.

If you decide to build this radio, here is what you will need:

1) A wooden "breadboard" also known as the circuit board.
2) A thin wooden or sheet metal panel or enough thin boards to make a box.
3) A large knob for the main tuning.
4) A smaller knob for the throttle
5) A paper toilet roll
6) 10 feet of 30 Ga. magnet wire
7) A few inches of 18 Ga. insulated wire
8) An MPF-102 (or similar) FET transistor
9) Two plastic variable capacitors (60 pF & 140 pF dual units) with shaft extensions from Scott's Crystal Radios.

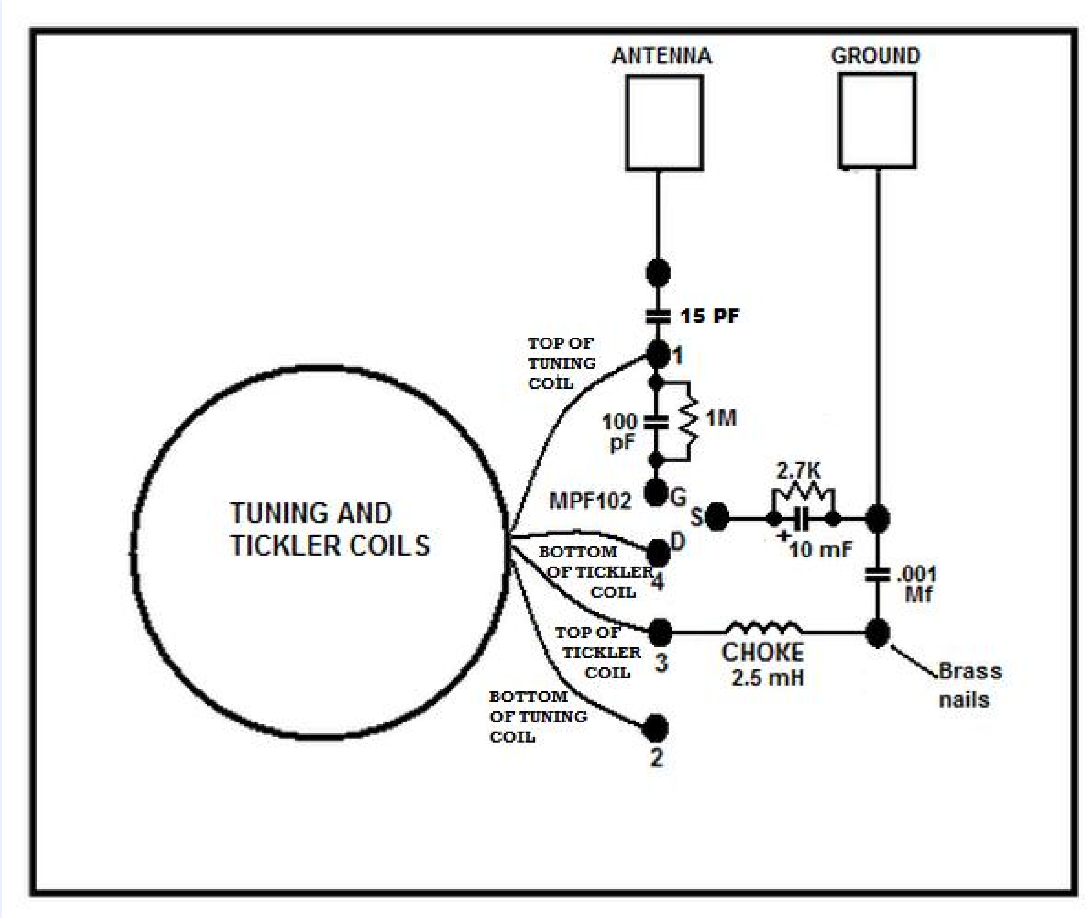
10) A 1 megohm resistor
11) A 2.5 mH choke coil. Tiny, low current chokes work great. Check e-bay.
12) A 2.7 K ohm resistor, 1/8 watt or larger.
13) A 0.001mF capacitor (50 volts or greater)
14) A 100 pF capacitor (50 volts or greater)
15) A 15 pF capacitor (1KV)
16) A 3.5 mm phone jack to fit your headphone or earphone plug
17) A 9 volt battery
18) A battery holder
19) Brass plated nails or small brass wood screws and two small screws for the Farnstock clips
20) Wood glue. Elmers white Gorilla Glue works great.
21) Two Farnstock clips.
22) My old Navy 600 ohm headphones work very well and so do my traditional 2,000 ohm headphones. Philmore sells a rugged and inexpensive 2,000 ohm earphone that works well too. "Crystal" type piezoelectric headphones or earpieces work well but you must place a 2,000 ohm resistor across them or they won't pass enough current. If you use low impedance headphones, you will need a 2,000 to 8 ohm audio transformer. Small transistor type transformers work fine. If you configure your radio with a transformer or a resistor in line with the battery, you will need to add an on/off switch or the radio will be on even if you aren't listening.

Tools you will need:

1) Drill and bits
2) Round file for enlarging holes
3) Screwdrivers to fit the screws you will be using
4) Ruler
5) Small hammer
6) Small saw
7) A low wattage soldering iron with a sharp tip.
8) Electronics grade (rosin core) solder. Having a jar of extra flux is really nice.
9) Needle nose pliers. I really love using hemostats for doing fine work.
10) A "Dremel" type grinding tool if your panel is thick and you need to counter-sink the phone jack.

Suggest layout and building instructions.

You will need some kind of front panel for mounting the tuning capacitor and the throttle capacitor. Perhaps the simplest construction would be to make up an 'L' shaped bracket with the components on the bottom board and the capacitors mounted above them. In that case, I suggest that you drive the brass plated nails in from the underside so that nothing protrudes through to the underside. However, the way I made my radio was how I made the original tube model back in 1958. I began by cutting up five 1/4 In. thick basswood (linden wood) pieces to make the crude wooden box that you can see in the pictures. I mounted the coil and most of the parts on the top deck and the tuning capacitors inside the box and on the front panel. The inside is also where the battery holder is mounted. As you can guess, the exact measurements of the wooden pieces are not important. You can figure out for yourself how large to make it based on the wood you use.



Top deck layout of my radio.
I mounted a phone jack, the tuning capacitor and throttle capacitor on the front panel below this deck.
The battery is mounted in a holder on the inside of the bottom deck.
The large black dots are brass plated nails.

Detailed building instructions

Begin the project with the coil form. Just as I had done 55 years ago when I built my "Boy Electrician" radio, I used a toilet roll for the coil form. Toilet rolls are still made of the same flimsy paper that must be soaked in a dope of some kind to make them stiff and so they won't fall apart. It seems that toilet rolls are larger in diameter (1.70 inch) than they were when I built my earlier radio because my modern roll will easily slip over my 1958 coil (1.55 inch). The next paragraph tells you the length of my main and tickler windings, but you should know that for small diameter paper rolls, you will have to use slightly more wire and thus more turns to get the same inductance.

To make the tuning coil, I began by drilling two tiny holes next to each other, and then two tiny holes 0.9 inches down the tube from them. I threaded the No. 30 wire through the first two holes so it was secure and wouldn't pull out then began to wind the tuning coil. It is always a good idea to make the tuning coil too long at first so that you will later have to to take some turns off. When I was done winding I had a coil that was 0.820 inches long. No, I didn't bother to count windings, but there was something like 85 altogether. If you use a smaller diameter paper roll, I suggest you wind 90 or more turns. Don't worry about making it a little too long because you will take some turns off later when you make your final adjustments.

To make the tickler coil, I drilled similar small holes side by side, threaded No. 30 wire through them and wrapped about a 10 turns on the roll, made two more small holes and threaded the end through them. Try to keep both the coils tight and regular with all the turns close together. There should be about 1/4 inch or so between the tickler and tuning coils, but the distance isn't too critical.

After you have the coils wound, it might be a good idea to paint some varnish or dope over them because you will be adjusting the number of turns later and you don't want the coil to come apart. I'll be saying more about this "cut and try" method of adjusting coils very shortly.

When your coils are complete, go ahead and smear on some glue around the bottom edge and glue it to the wooden circuit board as shown in the pictures. Just let the coil wires dangle for now.

Partly drive in the nails from the top of the circuit board if mounting everything on top or drive in the nails from the bottom all the way in if mounting everything inside the box. Use the photo and diagram as a guide to where and how to place the nails.

With tiny drops of glue at the edges of the variable capacitors, glue them to their panel with the shafts sticking out. The capacitors used in this project have two sections, a 140 pF and a 60 pF section. For the tuning capacitor, the two sections will be bused together with a piece of bare wire for a total of a 0 - 200 pF. For the throttle capacitor, you will use only the 60 pF section.

With the Dremmel tool and a grind stone, countersink a hole in the panel and make the wood thin enough to enable the phone jack to go through the panel and be screwed down with its nut. You may locate the phone jack anywhere you wish, but I found the lower left corner of the front panel an ideal place.

You will need some way to connect to the antenna and ground. It is up to you to decide what kind of connector to use, but I found that simple Farnstock clips are both inexpensive and very useful for this kind of thing. At any rate, you will have to mount them on your board so you can wire to them later.

Once you have the nails driven in, the antenna and ground connectors, the tuning capacitors, the phone jack and the coil all mounted, you can begin to mount the small components and wire everything up as follows:

1) Make up the gate tickler network by soldering a 100 pF capacitor across a 1 megohm 1/4 watt (or smaller) resistor.
2) Make up the source bias network by soldering a 10 mF electrolytic capacitor across a 2.7 kilohm 1/4 watt (or smaller) resistor.
3) Solder one end of the gate tickler network to the G (gate) nail as shown.
4) Solder the other end of the gate tickler network to the nail next in line above the G nail.
5) Solder a 15 pF capacitor from that nail to the one directly above it.
6) Solder a bare wire from that nail to the antenna connector.
7) Solder the end of the source bias network that is the positive side of the electrolytic capacitor to the S (source) nail.
8) Solder the other end of the source bias network to the nail to the right (grounded).
9) Solder a bare wire from that nail to the ground connector.
10) Solder a .001 mFd capacitor from that nail to the nail directly below it.
11) Solder one end of a 2.5 MH choke coil to that nail.
12) Solder the other end of the 2.5 MH choke coil to the nail to the left.
13) With fine sandpaper folded over, carefully remove the insulation from the wire coming from the bottom of the tuning coil and solder it to the nail labeled '2' as shown.
14) With fine sandpaper, carefully remove the insulation from the wire coming from the bottom of the tickler coil and solder it to the nail labeled '4' (or 'D') as shown.
15) With fine sandpaper, carefully remove the insulation from the wire coming from the top of the tickler coil and solder it to the nail labeled '3" as shown.
16) Carefully remove the insulation from the wire coming from the top of the tuning coil and tack solder it to the nail labeled '1' as shown, but only temporarily as this will be removed later when the coil turns are adjusted.
17) At the underside, run a wire from the positive side of the battery holder to one side of the phone jack and solder it in.
18) Run a wire from the other side of the phone jack to choke coil's nail on the right side. Wrap it around the nail and solder in.
19) Run a wire from the ground nail to the nail labeled '2', wrap it around the nails and solder each end.
20) Run a wire from the negative side of the battery holder to the ground nail and solder each end.
21) Run a wire from the '2' nail to the ground (center) tabs of both variable capacitors.
22) Run a wire from the two bused sections of the tuning capacitor to the nail labeled '1' and solder it in.
23) Run a wire from the 60 pF section of the throttle capacitor to the nail labeled '3' and solder it in.

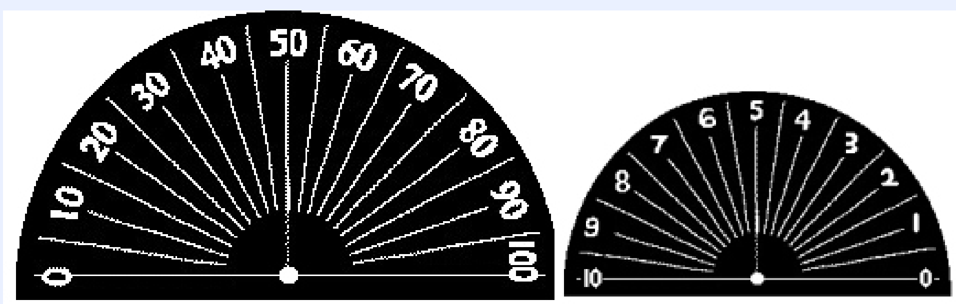
24) Identify the G, S and D leads on the FET, carefully wrap them on their respective nail with a long nose plier and solder them in.
25) Insert a 9 volt battery in the battery holder.
26) Rotate the tuning and throttle capacitors fully clockwise.
27) Connect an antenna and ground to their respective connectors.
28) Plug in a high impedance headset or earphone (no more than 2,000 ohms) and tune counterclockwise while listening for stations.
Adjust the throttle for best reception. Try to locate a station at or near the top of the broadcast band (1,600 to 1,700 KHz).

In the last step, your radio is unlikely to tune that high, so we must now adjust the number of turns on the tuning coil and we will do it as follows:

The old "cut and try" method radio electricians have been using for over 100 years

Getting just the right number of turns on your coil is something you will have to experiment with. When you search for a station you know is high up on the dial, you won't find it at first because your radio won't tune high enough. To get it to tune higher, you need to unsolder the coil wire at nail 1 and carefully unwind a couple turns of from the top of the coil. Cut off the excess wire length, solder the wire end to nail number 1 and try it again. You may have to repeat this step two, three or four times until your radio tunes high enough. I can't give you the exact number of turns you will need to take off because toilet rolls vary, so you will just have to "cut and try" to get the right number of turns. Here's what I suggest, adjust the number of turns of the coil until that 1600 station that is way up there on the top of the band is tuned in with the tuning capacitor no more than 90% fully clockwise. If your station is around 1400 KHz, adjust the turns on the coil so that the tuning capacitor is no more than 85% fully clockwise.

When you are done, you might want to make up the dials as shown below, cut them out and paste them under their respective knobs.

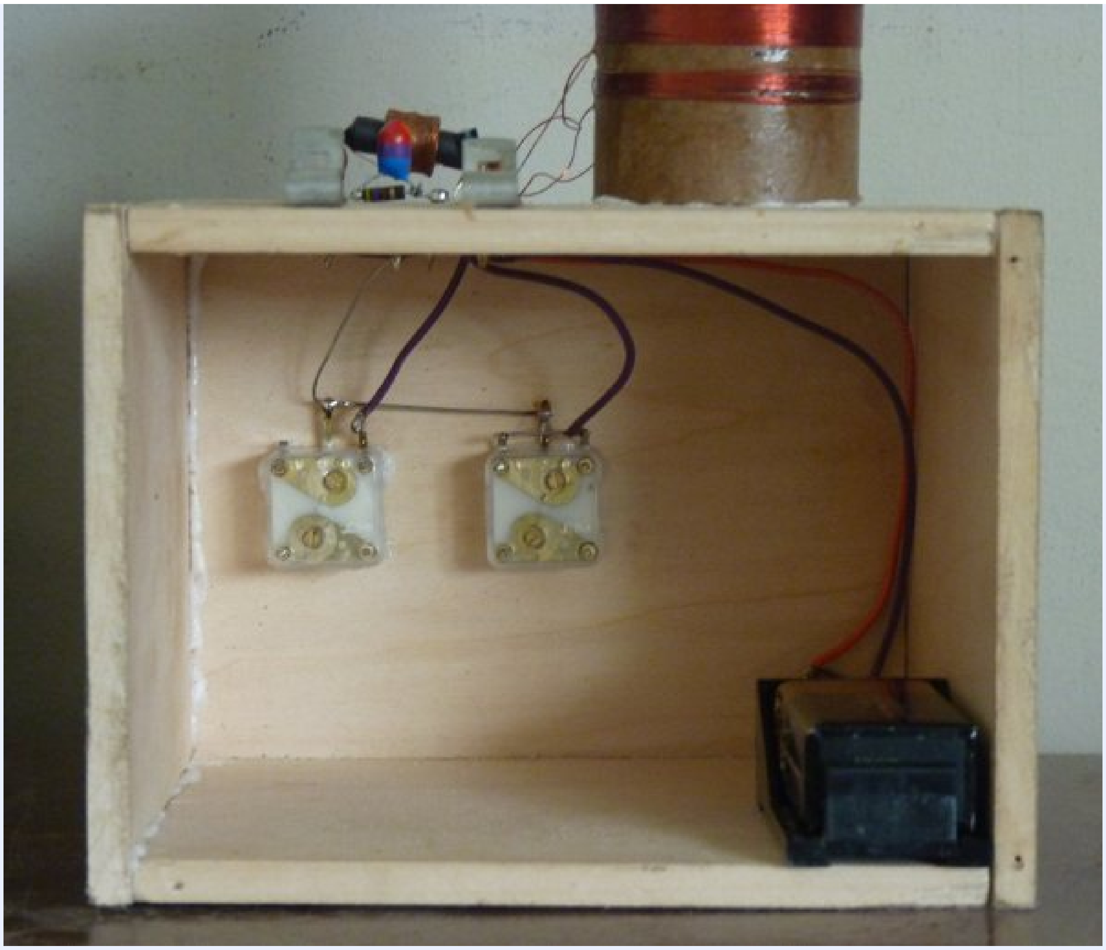


For the dials, you can print these images at a total width of 3 inches,
carefully cut them out and paste them on to the front panel under their knobs.

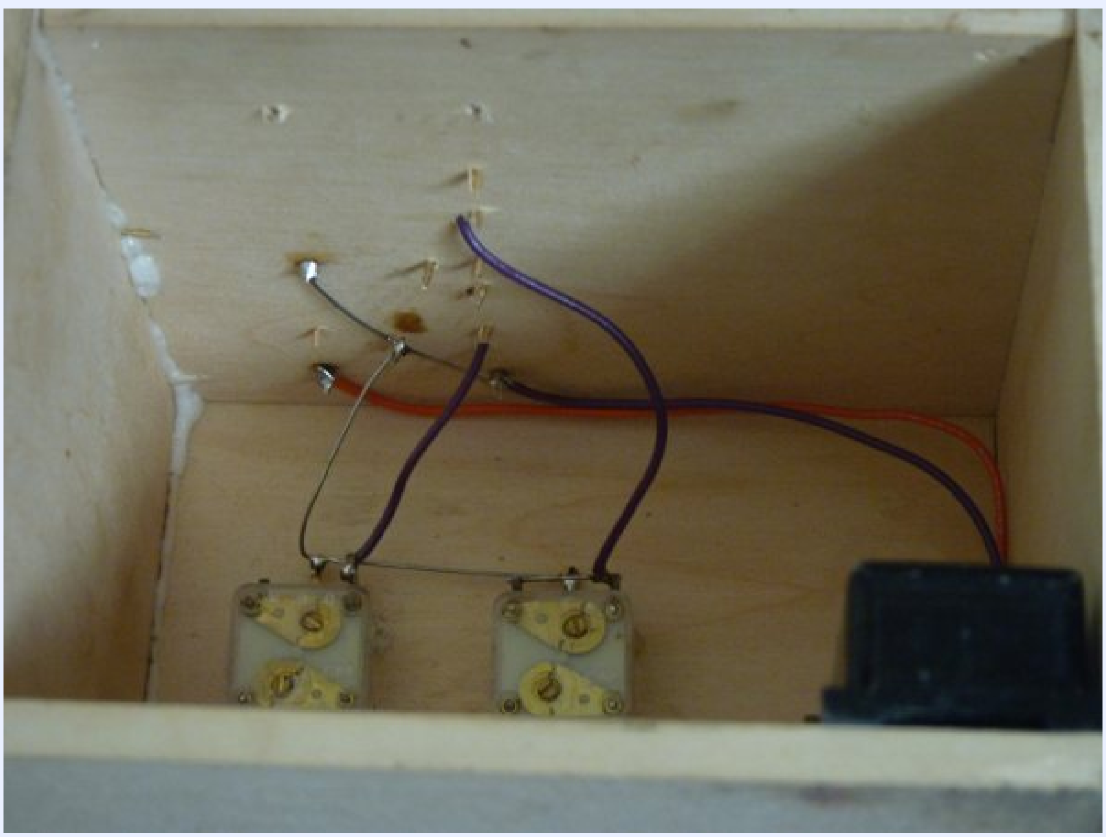
Photos of the completed project

Top deck with the coil and other components mounted.
Note that brass nails are driven into the wooden board and are used as termination points.
The antenna and ground connections are the clips on the upper right.
For old times sake, I wanted to mount the parts on the top deck. There is no reason you can't mount everything inside a box, just be sure your nails (or screws if you use screws) don't protrude through the bottom of the box.

The Geezerola front panel.
Station tuning in the center, throttle on the right, phone jack to the lower left.
As ugly as this radio is, if you are a boy or girl electrician, 50 years from now you will be very proud of it and you will want to display it in your living room. If you are an adult or geezer electrician, well, maybe you'll want to make it look a little nicer before you show it off.



Rear showing the battery and the variable capacitors.
The phone jack acts as an on/off switch and is behind the battery holder.



Underside wiring.
If you mount everything inside the box, drive the nails in from the bottom and solder to the tops of the nails.

An alternative design for the throttle control

A lady engineer from England has written to tell me that she built an Armstrong regenerative FET radio that requires a little more work to build, but looks ever so much better than my radio and requires no choke coil. She went back to the very early days of radio and designed a variable inductor (called a variometer) very much like those that were used in the days when variable capacitors and choke coils were rare and expensive. The fact is, most of the early radios used variometers, so this is a very interesting and historical version of the Armstrong regenerative radio.

This hansom radio radio has its battery, FET and other circuit elements inside the box while the tuning coil and the throttle's variometer are mounted on top.

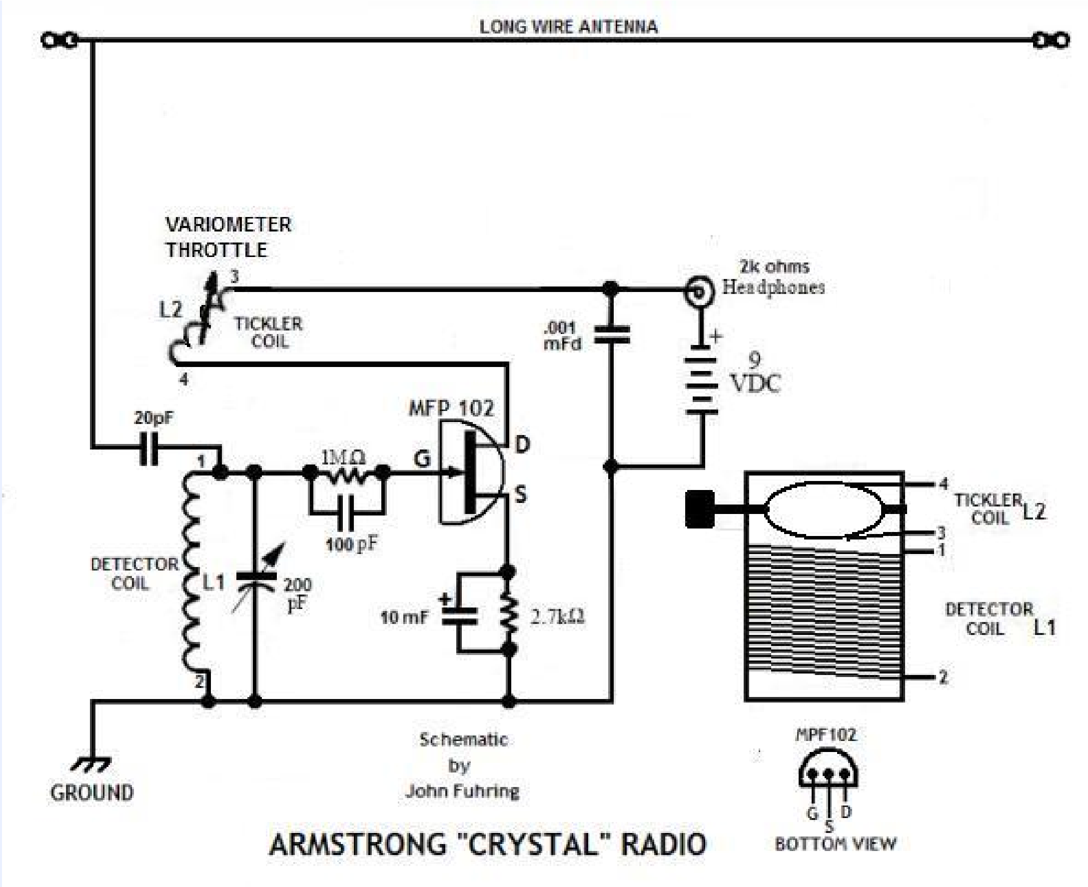
Here is a closeup of the variometer throttle with its control knob.
Notice that the variometer is set to about 45 degrees.

The variometer consists of a movable coil near or within another coil. As you probably know, when there is an alternating current flowing in a coil, an alternating magnetic field is set up and that magnetic field can be picked up by a nearby coil and a second alternating current is then created in the second coil. This is the principle of "mutual inductance" that was discovered by Michael Faraday back in the 1830s. Mutual inductance is a most important principle because everything from huge power transformers to tiny radio coils work on this very principle.

Now, when the two coils exactly line up, the magnetic field of the one carrying the current will "induce" or couple its magnetic field to the second coil most efficiently, but when the two coils are at a 90 degree angle, very little of the magnetic field is coupled and very little current is created in the other coil. Now, if you had a way to change the angle, by having one of the coils rotate above or within the other coil, you could vary the amount of "mutual inductance" or what is called "coupling" between those two coils.

In a tickler coil, varying the amount of coupling is called throttling. A fully throttled tickler coil would be at a 90 degree angle to the main tank coil so that there would be minimum coupling and therefore minimum regeneration (feedback). On the other hand, at some point, as the rotating tickler coil lines up with the tank coil, more and more feedback will occur as more and more signal is coupled from the tickler coil to the tank circuit coil and at some angle, oscillation will start.

As you can see, varying the angle between the two coils acts as a very effective throttle and the practical advantage of this is that you don't have to use a choke coil to isolate the tickler coil. Another advantage of the variometer (for us builders) is that they look so interesting and are fun to use, with one of the coils able to rotate about a shaft near or inside the other. Of course, the big disadvantage is that they are much more difficult to build compared to simply buying a small and very inexpensive variable capacitor. The second big disadvantage is the radio must be much larger to accommodate a variometer. With the tiny variable capacitors now available, you can make a radio in the fraction of the space required of a radio containing a variometer. In terms of performance, that is, how well they work to control the regeneration, the variometer throttle is every bit as good as the variable capacitor throttle.

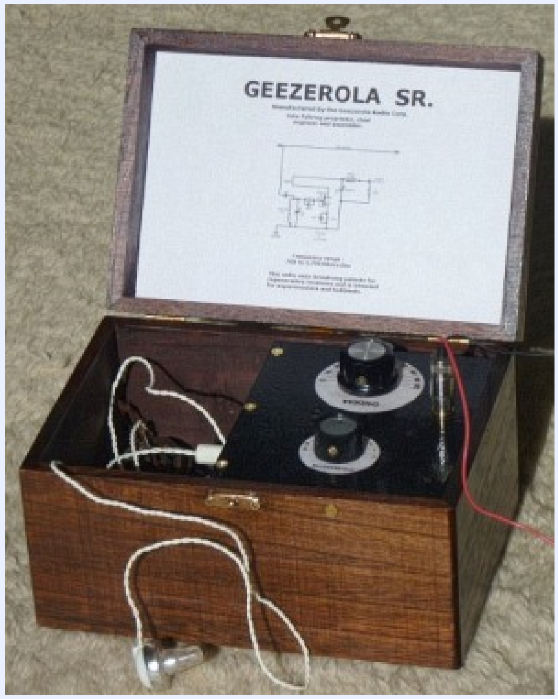


The schematic of my radio showing a variometer throttle

The aesthetics (or lack thereof) of my radio

Compared to the really beautiful works of art that some crystal radio builders have created, including the one above, you can see that my project is crude, really, really crude. To show you what I mean, right below here is a picture I captured from Jim Fredrick's crystal radio site showing one of his beautiful radios. Speaking of which, there are some really beautifully made radios on that site and I invite you to look them over.

Yes, this is a beautifully made radio, but even a crude
looking radio will perform well if it uses a good design..



To make a nicer looking radio, I built the Geezerola Senior and you can find a link to it at the end of this story.

Choosing a "clever" brand name for your radio
and a little history

The 1921 Aeriola Senior, the first commercial regenerative radio.
The first radio station, KDKA Pittsburgh, had begun operation just
a few months earlier to broadcast the 1920 November Presidential elections.

Only about 500 - 1000 people were able to hear the broadcast, but word quickly got out and caused an instant, nation-wide sensation. The radio station was owned by Westinghouse and this radio was made by Westinghouse. Isn't that a strange coincidence?
By the way, one of the reasons the Aeriola Senior is so much larger than my Geezerola Senior is because the tuning coil and the throttle coil are variometers and there are no variable capacitors used in this set.

Putting a "brand name" on your radio is optional, but it is kind of fun and you can call your radio anything you wish. The name I chose was "Geezerola" because it is a play on the name "Aeriola Senior" which was the very first one-tube Armstrong regenerative radio to hit the market in 1921. The name 'Aeriola,' meaning "music from the air," was later changed to Radiola in 1922 (probably because the name sounded too much like a certain body part). They were made by the Westinghouse Electric Co. for the newly formed Radio Corporation of America (RCA), which, through their system of patents and ruthless business practices, was to dominate radio design for the next 40 years. If you will look to the point just above the large tuning dial, you will see the glass bulb of one of the very first really good high vacuum tubes to be mass produced in America, the famous WD-11 triode. The radio has a tuning control, just as my radio does, it has a regeneration control, just as my radio does and it has a filament brightness control (upper left) which my radio doesn't need, otherwise the two radios are remarkably similar. By the way, most of these radios were later modified to use the cheaper and more rugged UV-199 tube, but that tube with its adapter base was taller and the lid wouldn't shut.

Anyway, I'm sure you can think of a cool sounding name for your radio that you can use to impress people with. How about this: ***The <your last name here> Aetherola Regenodyne*** or something equally pretentious that will bring a smile to the faces of those in the know. Of course, you and I both know that the famous Michaelson-Morley interferometer experiment and later Albert Einstein's Theory of Relativity cast serious doubts on the 19th Century *Luminiferous Aether theory* of electromagnetic propagation, and so it's kind of absurd to call your radio an "Aetherola" (music from the Aether), but how many other people would know that?

The way this radio works is pretty basic

and here's how it all works:

The setting:

Imagine that there is a radio station 10 miles away and that it that is broadcasting radio waves at 1,400 KHz.

Imagine that our radio station is broadcasting hundreds of watts of energy into space, but because of the laws of physics, the vast majority of that energy is lost to space. Imagine that we could somehow capture just a tiny amount of this energy with an antenna. Imagine sending this tiny amount of energy to some kind of a circuit where it would be amplified so that we could hear what is being broadcasted even if we were miles, maybe even hundreds of miles away. Imagine that we have a simple radio like the one above connected to a wire antenna.

(1) The passing radio wave from our station induces a tiny high frequency voltage on our antenna wire.
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(2) The high frequency voltage from the antenna is lightly coupled (by a 15 pF capacitor) to a tuned circuit consisting of the detector coil and its variable capacitor (seen to its right) called the detector tuning capacitor. The combination of the detector coil and the tuning capacitor is called a 'tank circuit' because it

can be thought of as holding a signal like a tank holds water.

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(3) By carefully adjusting the 0-200 pF detector tuning capacitor, the tank circuit will be right in tune with 1,400 KHz and a tiny 1,400 KHz alternating voltage (called the signal) will appear across the tank circuit circuit.

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(4) The tiny signal from the tank circuit is coupled to the gate (G) of the FET by the 1 megohm resistor and 100 pF capacitor combination called the 'gate tickler' network. The small signal at the gate of the FET causes relatively large changes in the high frequency current flow between the source (S) and drain (D) in the FET.

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(5) This high frequency current is wired to flow in the 'tickler coil' and it will produce its own magnetic field in the tickler coil. This magnetic field is close to the detector coil which picks it up and creates a 1,400 kHz voltage that adds to the original 1,400 KHz voltage from the antenna thereby amplifying the original signal.

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(6) This operation occurs over and over again so that the original signal is amplified hundreds of times. The way the original signal is amplified by being fed back on itself for more amplification is called 'regeneration' and the amount of regeneration (also called feedback) must be carefully controlled or it gets out of hand and the radio squeals.

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(7) Another advantage of feeding a signal back on itself is that the sharpness of tuning (called 'selectivity') is multiplied each time the signal goes through regeneration. This means that a simple tank circuit such as we have now is able to separate out a close by station so that it doesn't blend with the station we want to listen to. Crystal radios with one or two or even more tuned circuits can't achieve this kind of selectivity.

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(8) The control of high frequency current flow in the tickler coil is what controls the amount of regeneration and it is the job of the 'throttle capacitor' to throttle or control the amount of regeneration so that the regeneration doesn't get out of control. When the throttle is set just right, just before the circuit goes into runaway oscillation, the amplification of weak signals is at maximum and so is the selectivity of the radio. In many cases it is kind of amazing how nearby stations "disappear" as the regeneration is throttled up.

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(9) It should be realized that the 1,400 KHz AM radio signal consists of a strong "carrier wave" (that never varies in frequency), but it also consists of two "sidebands" that carry the voice or music. The strength and distance from the carrier wave of these sidebands is what a radio detector responds to when it creates music or voice audio from the AM signal.

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(10) While the AM signal is being strengthened by regeneration, the carrier wave and the sidebands mix to create an audio "heterodyne." Audio heterodyning occurs when different frequencies mix to produce a third subtraction frequency. For example, if a 1,400 KHz carrier wave mixes with a 1,401 KHz sideband, it will produce a 1 KHz tone. Since voice or music is simply a series of rapidly changing tones, mixing like this will produce our sound.

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(11) The audio signal produced by heterodyning the carrier wave with the sidebands causes the current flowing through the FET to vary just as the radio frequency waves (that we can't hear) cause the current to vary, but this current varies at a relatively slow rate that the human ear can hear. It is these variations in the current through this circuit that our magnetic earphones respond to to make sound waves.

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A little more theory
The difference between a vacuum tube and an FET

If you read the story of my 1958 Armstrong regenerative radio, you will see that the design of this FET radio and my original radio are almost identical. The only difference is that for this radio I am using a "solid state" device (the MPF102 FET) rather than a "thermionic" vacuum tube (the 1H4GT).

You may know that a simple tube like the 1H4 consists of a plate of metal called the anode, a grid-work of fine wire called the grid and a loop of wire called the cathode. In between those elements is nothing, nothing at all because that space contains nothing but a hard vacuum. When the cathode is made hot by passing a current through the wire loop, free floating electrons fill this vacuum and if the anode is made positive, current flows. Between the anode and cathode of the tube there is a grid, as mentioned, and this grid can set up an electric field that controls this flow of electrons very much like a hand valve controls a huge flow of water in a pipe. That is why the English and some other people call electron tubes "valves." When a small, weak signal voltage is

placed on the grid of the 1H4 tube, it creates an electric field that greatly effects the relatively heavy flow of electrons between the hot cathode and the anode and thereby it amplifies the weak signal. In Armstrong's regenerative circuit, the weak signal is amplified over and over again as it passes through the tube multiple times.

The FET does not have a vacuum in it, rather it has a tiny crystal of silicon. silicon crystals conduct electricity very poorly unless they have been made "dirty" by adding something like phosphorus to the crystal (the process is called "doping"). The doped crystal now becomes a good conductor of electrons just like the boiled off electrons of the cathode makes the vacuum between the cathode and anode a good conductor. Just as the grid of the tube can control the flow of electrons in the tube's vacuum by setting up an electric field between the cathode and anode, the "gate" of the field effect transistor sets up an electric field that causes a "depletion channel" to form in the crystal thus regulating the flow of electrons within the crystal. If the depletion channel is wide and deep, few elections will pass, but if the channel is shallow, lots of electrons will pass. As with a tube, the FET can be configured to take a very weak signal and boost it way up (amplify it). It doesn't matter if you are using a tube or an FET in an Armstrong regenerative circuit, a weak signal is amplified over and over again until the various sidebands and the carrier mixes to produce audio frequency sound that it is loud enough to hear in the headphones.

In many ways, you can think of a FET as a very tiny vacuum tube that doesn't get hot, but works pretty much the same as the tube. You can think of a FET as a tube who's cathode (called its "source") is always emitting electrons that flow to the anode (called its "drain") and, as is done by the grid in a tube, the electric field produced by the "gate" of the FET controls this flow. The only big difference is that with an electron tube, there is this big, beautiful and glittering Electropolis to stare into and as your mind's eye wanders through it, your imagination soars. No, FETs are tiny, black plastic things about the size of a booger and about as pretty (you can't even see the crystal), but they work nearly the same as a tube. FETs work as well or better than tubes, are a lot less fragile, use lots less power and will never burn out. Oh yeah, they are a whole lot cheaper and easier to get too. Handsome is as handsome does, I guess, but I do love tubes.

The importance of a good antenna and ground system

Antennas for listening to AM stations can range from tiny "loop" antennas that are extremely inefficient, but good enough for amplified radios, all the way to elaborate "long wire" systems dozens and dozens of feet long and high up in the air. The general rule was discovered by Marconi over a hundred years ago that the longer and higher the antenna, the better it is at capturing some of that energy that is passing by.

Crystal radios operate only from the energy they capture from an antenna, therefore a good antenna and ground system is vital for their operation. To capture enough passing energy so that it can be processed by a crystal radio's components and then come out as sound energy strong enough to vibrate the mechanism inside the earphone, the antenna needs to be as long and as high as is practical.

With this little regenerative radio, because it is ever so much more sensitive than any crystal radio, you do not need an antenna nearly so long and high as you need for the crystal radio. For local stations, a loud signal may be heard using antennas as short as 12 inches and distant stations at night many times come in well with antennas no longer than 10 feet.

One thing this radio shares in common with a crystal radio is the need for a ground connection. Right now, I clip my radio's ground to the metal case of a radio that is plugged into the wall and it works great. Water pipes work really well too. The fact is, clipping the ground of this radio to just about any piece of metal seems to work as a ground, even another long piece of wire. Be absolutely certain that you NEVER connect the ground to a hot lead that is carrying AC voltage.

Tuning this radio for maximum sensitivity and selectivity

Of course, this radio, as do all regenerative radios, can go into self-oscillation if the throttle is turned up too high (set too far counterclockwise). Having the throttle set too high produces the infamous squeal that these radios are so notorious for and which, in the old days, caused them to be less than popular. The point of adjusting the throttle is to make it so the radio is just on the very knife-edge of going into oscillation. Just before oscillation, just before the audio sounds distorted, is when the radio reaches its peak amplification (best sensitivity) and when it tunes to its peak sharpness (best selectivity).

You can use the squeal of too much regeneration to your advantage once you learn the tricks. To find a weak

station you want to listen to, turn the station tuning knob to a little lower than where you expect to find your station. Turn the throttle clockwise until you hear nothing and then counter clockwise until you first start to hear a faint "rushing" sound. If you tune upward, you will hear stations as whistles and squeals. Zero in on one of the squeals and try to make it as low in frequency as you can (this is called "zero beating") then adjust the throttle until the squeal or distortion just barely disappears. You will notice that if you change the tuning knob clockwise (tuning up in frequency) the squealing will start again and you can't go too far before you have to adjust the throttle clockwise to tone down the regeneration. By going back and forth between the tuning knob and the throttle, you can hunt across the dial for the station you want to listen to, but it is usually best to start low (counter clockwise) and work high (clockwise). Actually, it is a lot easier to learn how to operate a regenerative radio than this description would imply. Learning how to use the regeneration control is one of the fun aspects of this radio and soon you will become expert at it.

To get good sensitivity while maintaining reasonable selectivity, I find that a 10 picofarad capacitor works well to couple the antenna to the input tuned circuit. Even with this relatively light coupling, strong local stations might tend to interfere with stations that are near the same part of the dial. If this happens, I suggest you use a short antenna, maybe only 5 feet long, and that way the tuning will be very sharp. I think you will be surprised that even even such a short antenna will still bring in stations quite nicely.

By the way, if you change from a long antenna to a short antenna, the tuning will be shifted and you will have to rotate the tuning knob counter-clockwise (add more capacitance) to tune in a particular station. If you change from a short antenna to a long antenna, you will have to rotate the knob clockwise (remove a little capacitance) to tune in that same station. Because the antenna has an effect on the tuning, the dial can't be marked as accurately as a superheterodyne's dial and that is why most crystal and regenerative radios do not have frequency markers on their dial.

The best time of the day to have fun with these kinds of radios

During the daytime and during the summer months, about all that can be received with a little set like this is local broadcasting. On the other hand, after sundown (on most evenings), electrified layers way up high in the outer fringes of our earth's atmosphere (the so-called "Ionosphere" also known as the "Thermosphere") allow radio waves from far away to be bent back down to the ground. Under ideal conditions, radio stations which are 200 to 300 (sometimes even more) miles away may be heard loudly and clearly. This long distance "refraction" or bending of the radio waves back to earth (a process called "skip") makes it possible to hear these distant stations, but it isn't like listening to the station next door. This "skipping" of radio waves off electrically charged layers in the upper atmosphere makes these signals subject to all kinds of strange things including interference from even more distant stations, fading in and out, some odd sounding distortions and sometimes there is even an echo effect. These so-called "propagation effects" can be annoying, but if you just wait a few seconds or minute or so, the signal generally returns.

Building and operating this radio gives insights into science and technology

If you build a simple regenerative radio like this one, you will learn about amplification, feedback loops and learn about the demodulation of radio frequency signals. You will learn something about the operation of field effect transistors and tuned circuits. You will learn something about antennas and ground systems too. You will learn about how microwatts of power can be picked up and heard loudly and clearly due to the extreme sensitivity of the human ear.

In addition to all that, this little radio will provide a motivation for you to learn something about atmospheric physics and solar physics and, if you really want to get into it, a branch of science called "magnetohydrodynamics." By building and operating one of these radios you will hear for yourself the amazing way electromagnetic waves behave at the top of our earth's atmosphere under the influence of our nearest star, the sun. None of this is magic, it is science, but it is so amazing that it almost seems like magic -- the magic of science.

I think that listening for yourself, to hear what Nature is doing to these signals way up in the sky, is part of what makes listening to the Broadcast Band at night so interesting. There is a certain randomness to this skip that is explained by solar astronomy and high altitude geophysics. Scientists and engineers all over the world closely monitor our local star and measure it for electrical and magnetic activity. Reports and prediction tables are compiled by various scientific agencies and all this stuff is available on the Internet. You can study and test these predictions for yourself with your radio and by doing so, you are participating in a scientific observation in

your own little way.

How it all began

This easy to build yet effective radio operates on the same principle as the early radios of the 1920s and as I've mentioned, building it will teach you some important lessons in radio electronics, but building this radio won't teach you about how radio began. Radio began in 1865 with one of the most brilliant person who ever lived, but who today is virtually forgotten. Maxwell, through his complex and brilliant equations was able to show that light was an electro-magnetic wave phenomenon and that visible light was only a tiny part of the huge electro-magnetic spectrum. This set off a race among scientists to see if Maxwell was right and if he was, if anything useful could be done with these electro-magnetic waves.

Except for light, electro-magnetic waves can't be seen or heard, so the first order of business required that they had to somehow be proved to exist and then there had to be devised ways to use them in a practical way. The way to detect the presence of electro-magnetic waves longer than light waves, in the so-called radio spectrum, is with a "radio detector" and so to help to teach you about the earliest radios, I have written a story about the very first really practical radio detector, the coherer detector. In that same essay I also mention how early detectors came and went as radio science progressed. I have a lot of side stories in there too that I hope will give you a more full understanding of how radio got started and what it was used for in the early days.

Here and at the end of this article there is a link to my essay on the earliest forms of radio that will give you a good background in basic radio technology: **The Coherer and other Detectors used in early radio** I think it is important that everybody interested in this sort of thing knows about this early technology and something about the people who made our modern technological world possible through their development of radio science.

How far we have come

Exactly 100 years ago Edwin Armstrong used an expensive and unreliable Audion triode tube in his first radio. Armstrong's design didn't catch on at first, but his ideas set the stage for many great advancements in radio. Ten years later in 1921, when my mother was a young girl, everyone was eagerly listening to this wonderful new entertainment and almost everybody was listening with crystal sets, but just ten years later, the crystal sets were gone, replaced by powerful vacuum tube radios that were able to bring in stations from all over the world. In a relatively short span of time, the time since my grand parents were young in the 1890s to my parent's time, to this very moment, consider just how far we have come with radio, television, GPS, cell phones, satellite broadcasting, wireless Internet, interplanetary missions to space and so much other allied radio technology. Consider too that it all started with simple little radios very similar to the one this story is about.

Conclusions:

People love to build simple radios and they are a lot of fun to get working, but let me say this right now, if you are going to go to the bother of winding a coil and putting together a little radio, you will want performance that makes the effort all worth while, so please don't bother building an "ordinary" crystal radio. Do yourself a favor and build this little radio. You will have something that goes together quickly, uses only ordinary parts and works hundreds of times better than anybody's crystal radio. To top it all off, you can do nighttime Broadcast Band DX'ing without the huge outside antenna that a regular crystal radio must have.

By the way, just recently, I compared the performance of this little FET radio with my 1958 vacuum tube radio. Both radios were connected to a short antenna only five feet long. I was surprised that the performance of both radios were nearly identical in every respect. In the evening I could pick up and listen to KGO in San Francisco (200 miles away) equally well. When I experimented with the two radios several days earlier I thought the FET radio was superior because it seemed louder when connected to the long wire antenna I use for my crystal radios. Actually, using an antenna that long with these radios is not a good idea and they actually seem to work better with much shorter antennas.

To any young person reading this, let me say that any little radio you build should be something you are proud of showing to others and it should be something you will proudly display (and maybe even write an Internet story about) 50 or more years from now. I sincerely believe that this little Armstrong "crystal" radio is just such a project. In my opinion, it is a worthy successor to the Boy Electrician radio I built in 1958 and of which I am still very proud.

Why you might want to have second thoughts about building this radio
(These are my personal opinions that you are not obliged to agree with and you may skip down if you wish)

There is something that should be considered when thinking about having your young people build any kind of AM radio and what I'm referring to is the unpleasant realization that, in many places in the U.S., there is absolutely nothing on AM radio that is (in my opinion) good for young, developing minds to listen to. Many local broadcasters pander to the most disgusting right-wing propaganda and Fundamentalist religious crap. Anyway, it is my opinion that persons wishing to direct young people into building a simple AM radio should carefully monitor their local AM broadcasting for the kind of trash I'm taking about. If the local airwaves are full of this trash, they must ask themselves: would building this kind of a project likely help or harm their young people? I think building an AM radio can have the potential to do more harm than good if your area is dominated (as mine is) with this sort of trash broadcasting. Now, on the other hand, if you actually WANT your kids to be exposed to religious or political propaganda before before their minds are sufficiently developed to resist brainwashing, then ignore this warning.

Of course, this applies to adults wishing to build one of these radios too. Is it really worth the expense and especially the effort to build a crystal radio when there is nothing to listen to? I did it strictly for the technical challenge, but certainly not to listen to local entertainment.

All this aside, if you decide build this radio, I think you will have a lot of fun and will learn a lot. Just remember that for about the same money you can get a MP3 player with an FM radio and 8 gigs of memory. While the MP3 player is a better deal, listening to it won't teach you anything about electronics. However, the horrible trash that's on AM radio has a well deserved reputation for making its listeners stupid and crass while listening to classical music through your MP3 player just might make you smarter and highly cultured, but it's your choice.

The best use I have found for my Armstrong "crystal" radio is to spend a few minutes at various times of the day and night (especially at night) listening to see what distant stations are coming in. I listen just long enough to discover where a station is because it's fun to monitor the condition of the "skip" off the Ionosphere, but that's all I'm interested in. I sure am NOT interested in their programming.

Now, having said all that, locally we have two strong Mexican music and call-in stations near the top of the dial. Those who understand Spanish and like Mexican music would really enjoy using this little radio because of this. I tune those stations in from time to time because sometimes it's fun to listen to polka music or chuckle at the extremely maudlin lyrics of some obviously heartbroken singer. Even though I don't speak a word of Spanish, sometimes it is pleasant to listen to how polite the radio host is to his call-in listeners and how he lets them do all the talking without haranguing them politically. I only wish the English language AM stations had such polite hosts who aren't filled with all this right-wing and conspiracy theory, hate-talk and don't have to be telling everybody all day and all night long about how hateful their idea of their god is.

Some final words

Can a radio such as this be modified to operate on the shortwave bands? Of course it can. To tune to the higher frequency shortwave bands, all you have to do is use fewer turns on the two coils, especially the tuning coil. If I see that there in much interest in a shortwave version of this radio, I'll include instructions for winding coils with fewer turns, but until then, you can experiment for yourself. One really effective and easy way to adjust the turns on your tuning coil would be to connect a frequency counter to the antenna and ground, put the throttle into oscillation and read the frequency. Adjust the number of turns of the tuning coil until you are in the band you want to be and adjust the tickler coil until the throttle works smoothly. Believe me, experimenting like this is a lot of fun.

By the way, if you build a radio based on what has been presented here, please drop me a line and describe it to me and, if you can, attach some pictures. I'd sure appreciate it if you would tell me how much you like the radio and how it performs for you. You can write me directly at my geojohn.org mail address.
Good luck.

The End

Having arrived this far, obviously you have a superior attention span and reading ability that far exceeds that of the majority of web users. I highly value the opinion of people such as yourself, so I ask you to briefly tell me:

Did you enjoy this article or were you disappointed?

Please visit my guest book and tell me before you leave my website.

If you have any detailed comments, questions, complaints or suggestions, I would be grateful if you would please **E-mail me directly**

You might like to read the story of my Armstrong regenerative radio that tunes shortwave and uses an FET for the detector,

My Regenerative Shortwave Radio.

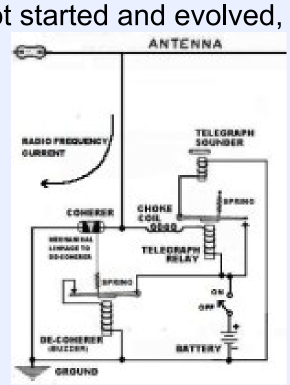
or perhaps you would like to read the article on

The Armstrong regenerative radio I built in 1958

If you are looking to build something with the same great performance of these little regenerative radios, but looks a whole lot nicer, I would like to suggest

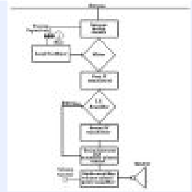
The Geezerola Senior radio

For more background on how early radio got started and evolved, perhaps you would like to read my essay on



The Coherer and other Detectors used in early radio

I have written a little essay you might like that explains some of the principles behind



[How The Armstrong Superheterodyne Radio Works]

or you can

Select another really entertaining radio article

or, as a last resort, you can

Return to my Home Page and look for something else

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Design and Realization of a Dual Wide Band Printed Monopole Antenna for WiFi and WiMAX Systems

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Abstract

A Printed monopole antenna was designed and manufactured with the wideband performances in two frequency bands. The antenna is compatible with WiMAX and WiFi standards. After reviewing a couple of literatures, the antenna was designed, analyzed and proven for two central frequencies, 2.5 GHz and 5.6 GHz, with much improved bandwidths. Finally, the antenna was manufactured with the overall size of 4 cm × 4.4 cm on Rogers (RO4003) substrate. The antenna is made into three L-shaped radiators. A 50 Ω microstrip feed line connects the port to the two L-shaped radiators of different lengths, thus providing two frequency bands. An inverted L-shaped radiator is printed on the less radiation upped side, to tune the antenna for wide band performances. The raised problem was solved with the integral equation solver of the Ansoft high frequency simulator structure (HFSS-IE). Optimal results are presented in this article: the simulation results in comparison with measured results. This antenna prototype's overall dimensions would be readjusted according to any industrial and manufacturing requests.

Keywords

HFSS-IE, Wideband Antenna, WiFi, WiMax

1. Introduction

Printed circuit board (PCB) antennas, notably most of patch antennas suffer from narrow bandwidth and low-power capacity [1].

Disadvantages encountered with Printed microstrip antennas [2]-[8] can be overcome with Printed monopole antenna, notably the narrow bandwidth which limits their uses in modern wideband wireless applications.

Considering the best of HFSS-IE simulator over normal HFSS [9], HFSS-IE simulator has been the selected design tool. The appreciable simulation results motivated us to manufacture this antenna which finally presents coherence while simulation results are compared with measurements.

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As applications, this antenna would be utilized for Wireless Local Area Networks (WLAN) systems based on IEEE802.11 as well as Wireless Metropolitan Local Area Network (WMAN) systems based on IEEE802.16a standards.

According to [11] [12], WiMAX systems based on IEEE 802.16a standards are compatible with bands ranging from 2 GHz to 11 GHz, expecting the bit rate from 70 to 100 Mb/s. The literature clarifies that wideband (WB) and ultra wideband (UWB) communication systems have received great attention in the wireless world due to their merits such as high data rate, low cost for short range access and remote sensing applications [13] [14].

In this paper, the reader is noticed that WiFi is interchangeable with WLAN while WiMAX is interchangeable with WMAN.

2. The Proposed Antenna Design and Results

Antenna is one of the most essential elements that characterize wireless systems.

A transmitted signal is considered UWB if the return loss' absolute bandwidth at −10 dB, exceeds 500 MHz [15]. Printed monopole antennas have been characterized with many possibilities for both wideband and UWB performance [13]-[16].

A couple of monopole antennas were surveyed such as inverted F [17] [18], inverted L [19] [20] and snake-like [21].

2.1. Design Methodology and the Proposed Antenna

HFSS-IE Simulator is available with HFSS version 14 and above. HFSS-IE is based on 3D full wave method of moments (MoM) electromagnetic Integral Equation to evaluate the surface currents of the object in question; then it calculates radiation and the scattering fields using the derived current [9] [10].

In our design, **Figure 1**, the shorter L-shaped radiating element is meant for the frequency band with resonance at 5.6 GHz while the longer L-shaped radiating element corresponds to the frequency band whose resonance is at 2.5 GHz. To tune the antenna for WB around 2.5 GHz and for UWB around 5.6 GHz, an inverted L radiator is printed on less radiation upped area of the antenna.

2.2. Simulated Results and Impedance (Z) Parameters

The return loss (RL) is such an important antenna characteristic that, throughout the design process, the RL is analysed to decide on the necessary bandwidth performance requirements. According to [22], the RL is defined as a measure of how much of the available power is not delivered to the load; a matched load has a zero reflection coefficient (Γ = 0) and thus has an infinity RL.

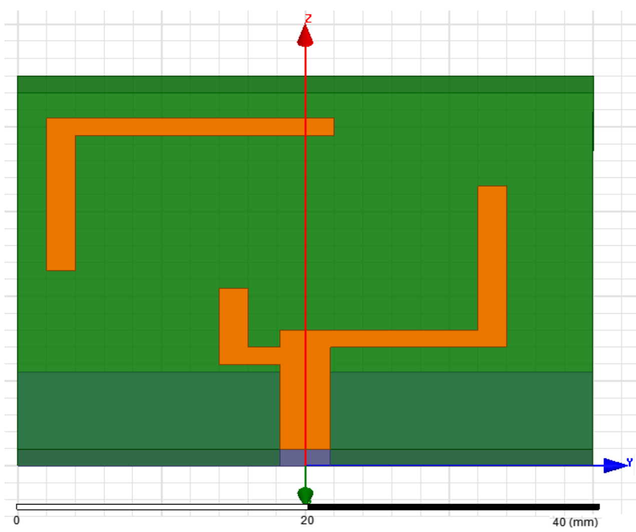


Figure 1. Three dimensional (3D) view of proposed antenna.

$$\mathrm{RL} = -20\log|\Gamma|\,\mathrm{dB} \tag{1}$$

After all the parametric analysis and optimization, our design model's RL is presented in **Figure 2** and each band's impedance parameters are measured according to **Figure 3**.

The Smith Chart, **Figure 4**, shows the perfect matching of antennas' impedance with the 50 Ω feed-line, for both $f_1 = 2.5$GHz, and $f_2 = 5.6$ GHz.

Figure 5 and **Figure 6** show the radiation patterns while **Figure 7** and **Figure 8** show the radiation fields overlay and surface currents distribution for both frequency bands.

2.3. Total Efficiency and Voltage Standing Wave Ration (VSWR)

The antenna total efficiency is defined as "the ratio of radiated power to the incident power, which is approximated to e_T [23], such that

$$e_T = e_r e_c e_d \tag{2}$$

where:

e_T is the total efficiency;

e_r is the mismatch efficiency, such that

$$e_r = 1 - |\Gamma|^2 \tag{3}$$

e_c is the conduction efficiency;

e_d is the dielectric efficiency;

$e_{cd} = e_c e_d$ is the antenna radiation efficiency.

Γ is the voltage reflection at the input antenna terminals,

$$\Gamma = \frac{Z_{in} - Z_0}{Z_{in} + Z_0} \tag{4}$$

Z_{in} is the antenna input impedance;

Z_0 is the transmission feed line's characteristic impedance;

The voltage standing wave ratio (VSWR) is generally referred to as the measure of antenna impedance matching with the feed line's impedance. Mismatches result in standing waves (SW) along the feed line. VSWR

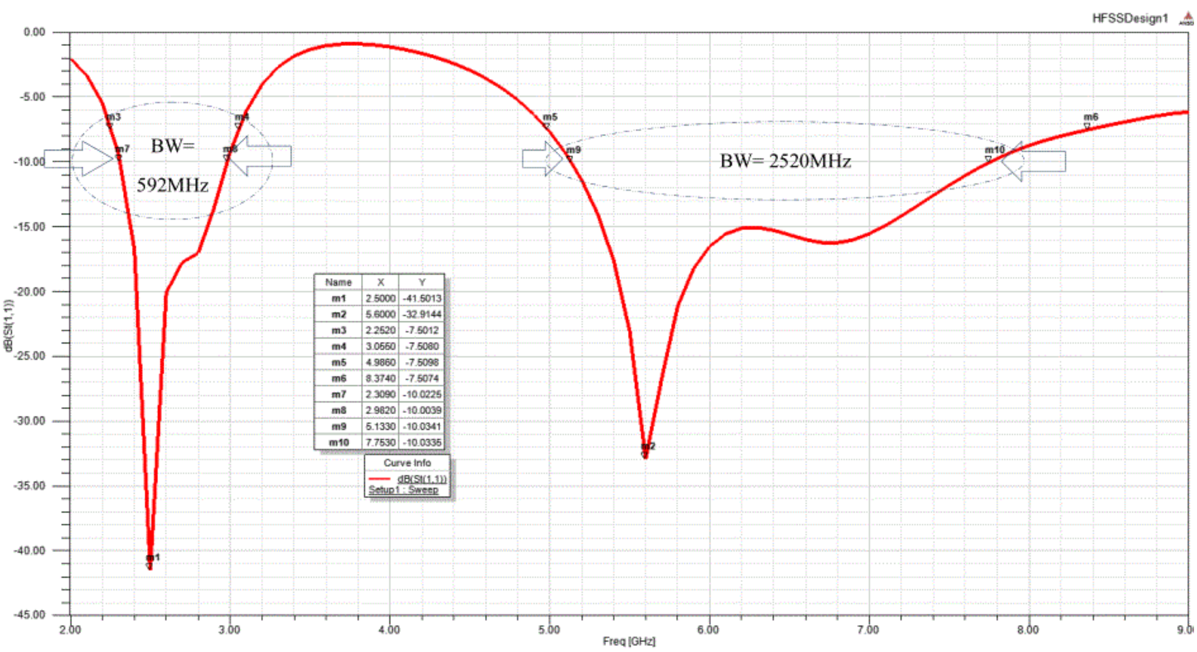
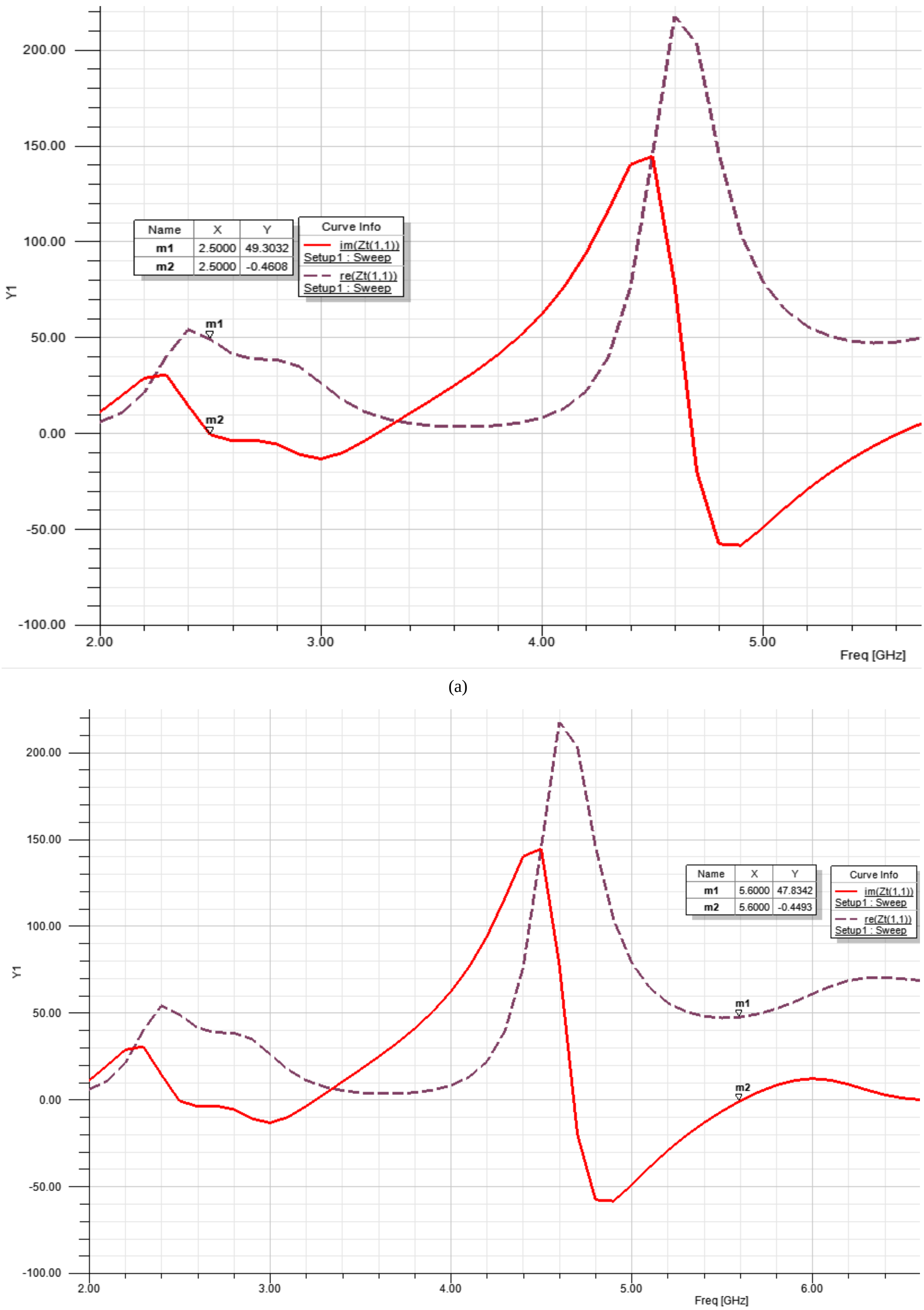


Figure 2. The simulated RL.



(a)

(b)

Figure 3. Impedance (Z) parameters: (a) for 2.5 GHz band; (b) for 5.6 GHz band.

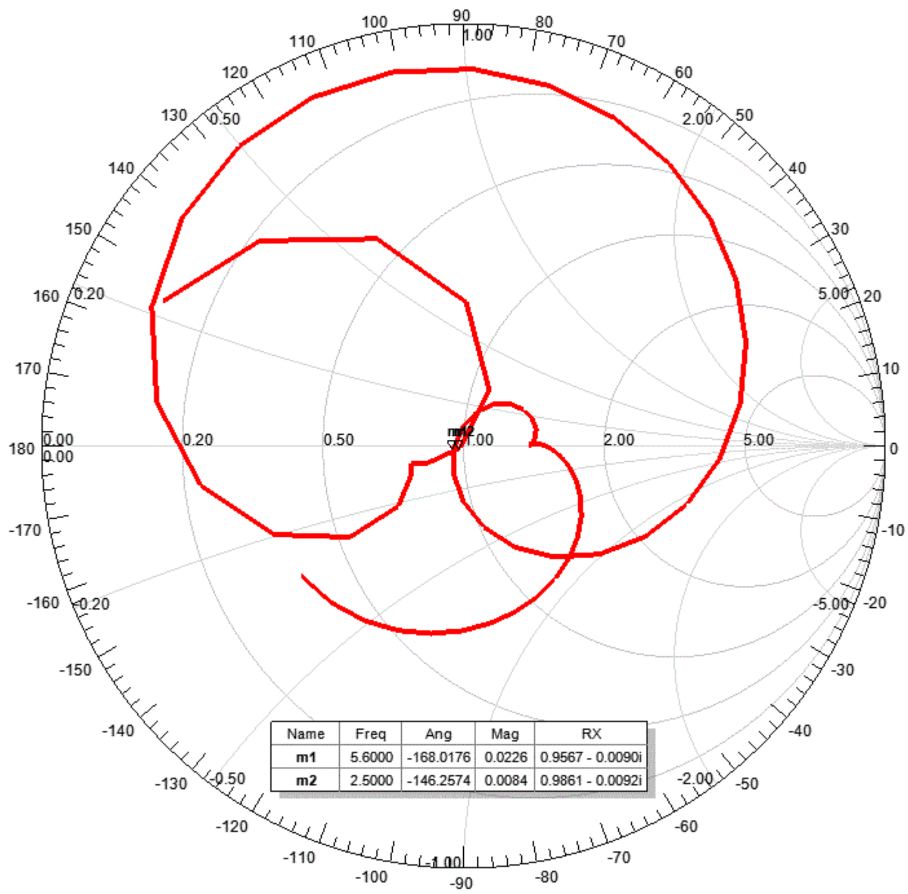


Figure 4. The Smith Chart's impedance measurement.

is mathematically defined.

$$\mathrm{VSWR} = \frac{1+|\Gamma|}{1-|\Gamma|} \tag{5}$$

In case of our design, the antenna radiation efficiency (e_{cd}) is assumed unity since the antenna is simulated under perfect electric conduction (PEC) boundary and measurements after implementation were done under well isolated environment; which means the total antenna efficiency evaluated here is equal to the mismatch efficiency.

Thus, referring to the measured antenna impedances in **Figure 3**; keeping in mind that the standard impedance for the microstrip feed-line is 50 Ω, the total antenna efficiency is now calculated for both 2.5 GHz and 5.6 GHz respectively, according to Equations (3) and (4); the VSWR is computed according to (5).

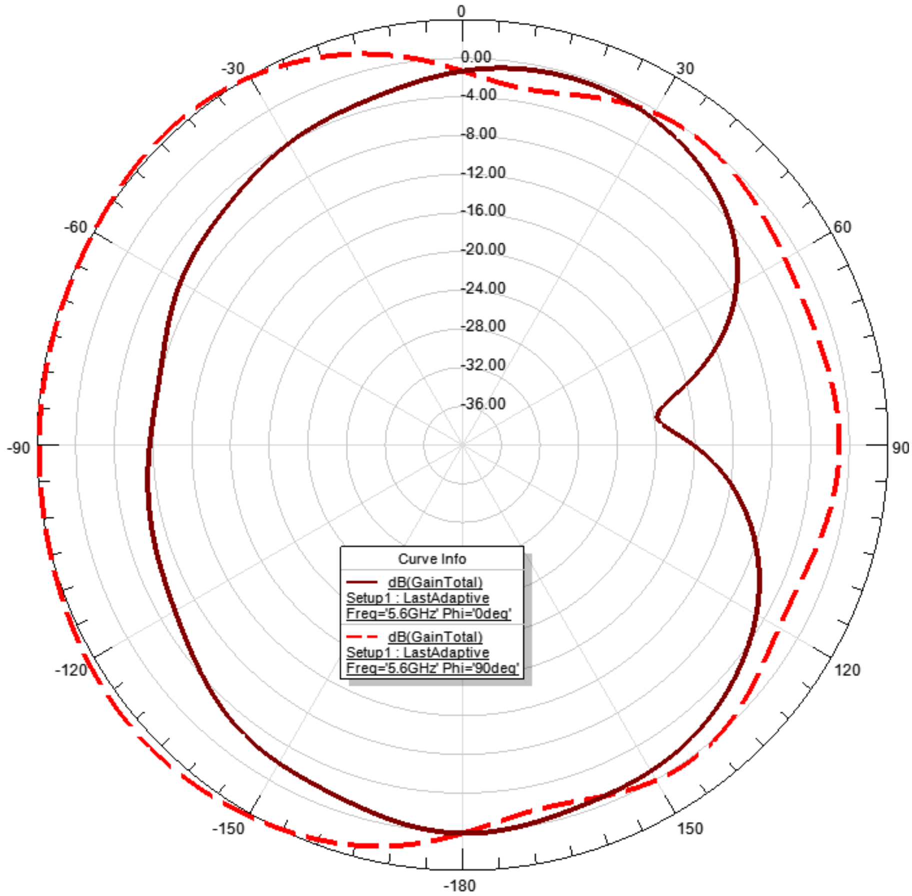
- ☐ When the antenna is operated at 2.5 GHz,

$$\Gamma = \frac{49.3 - j0.46 - 50}{49.3 - j0.46 + 50} = -(0.007 + j0.0046)$$

- ✧ $e_{T(2.5\mathrm{GHz})} = 1 - |\Gamma|^2 = 99.16\%$
- ✧ VSWR = 1.017.
- ☐ When the antenna is operated at 5.6 GHz,

$$\Gamma = \frac{47.83 - j0.45 - 50}{47.83 - j0.45 + 50} = -(0.0221 + j0.0045)$$

- ✧ $e_{T(5.6\mathrm{GHz})} = 1 - |\Gamma|^2 = 97.74\%$
- ✧ VSWR = 1.046.



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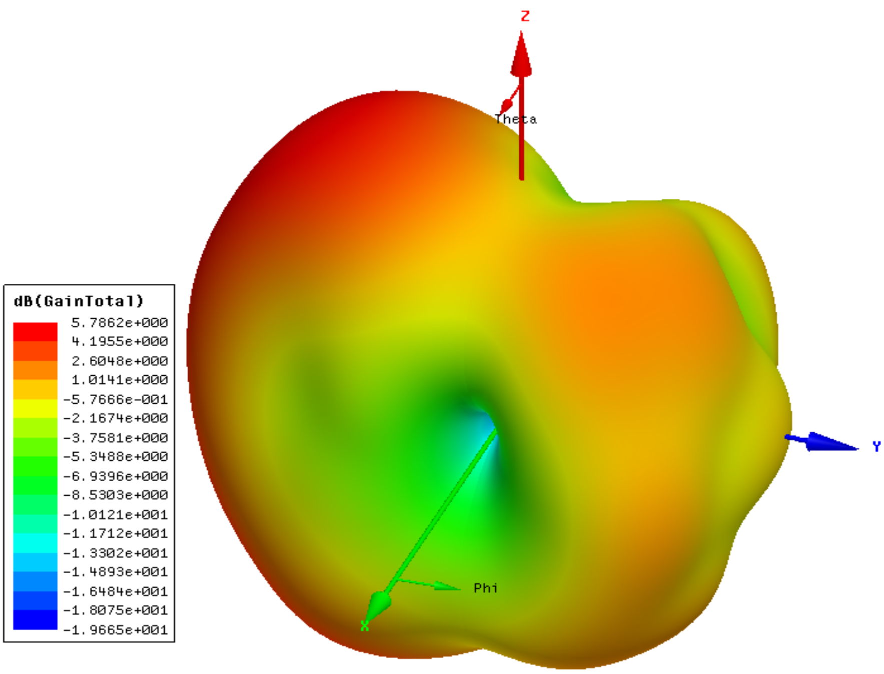
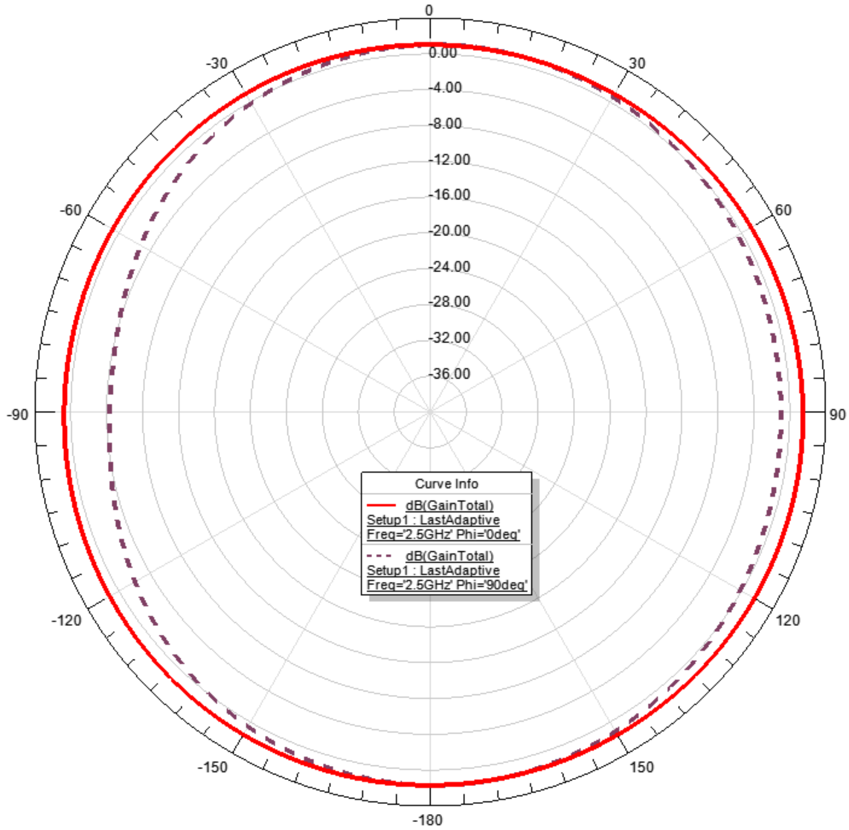


(b)

Figure 5. Radiation patterns at 5.6 GHz (a) E-H Radiation Pattern; (b) 3D Polar plot.



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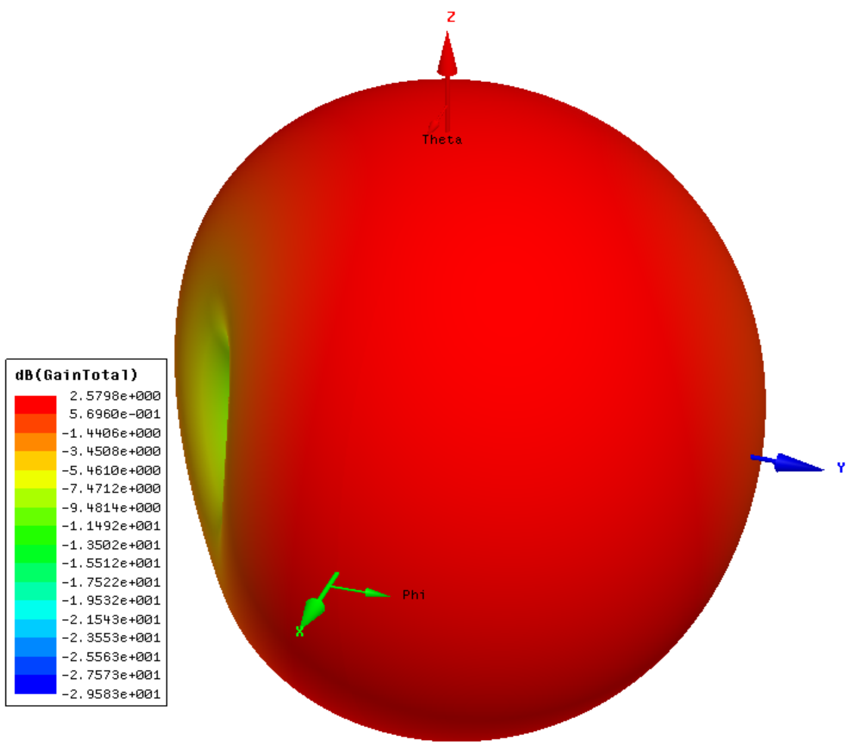
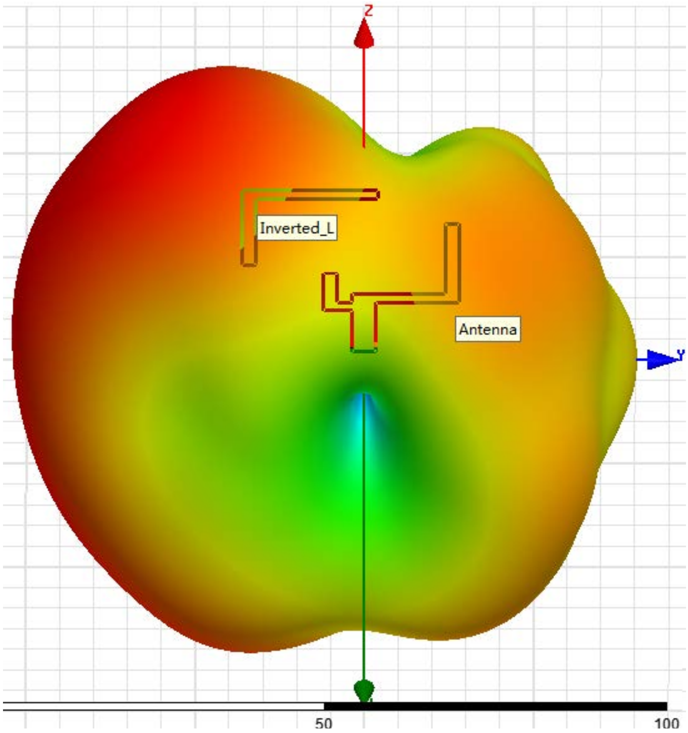


(b)

Figure 6. Radiation patterns at 2.5 GHz (a) E-H Radiation Pattern; (b) 3D Polar plot.



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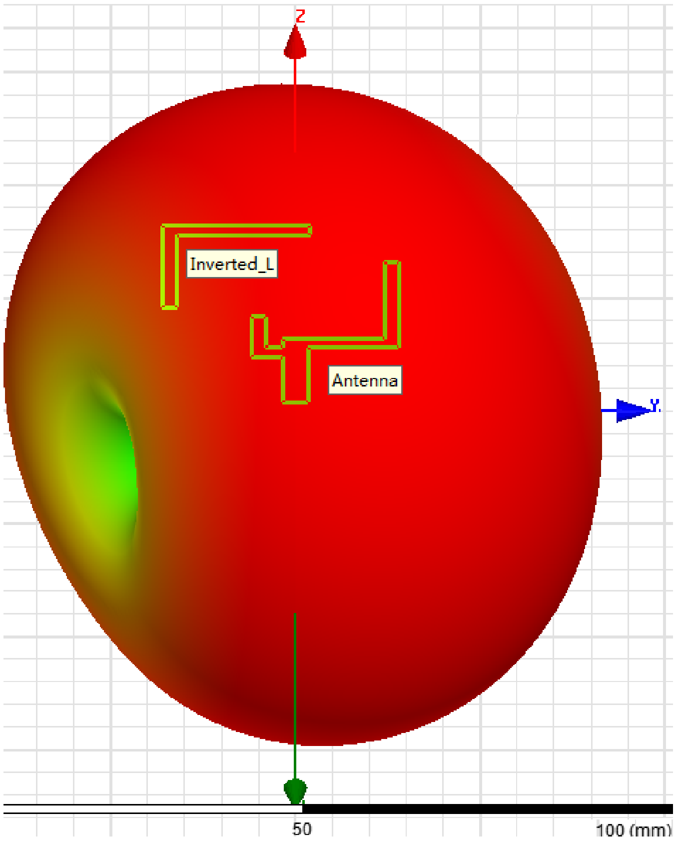
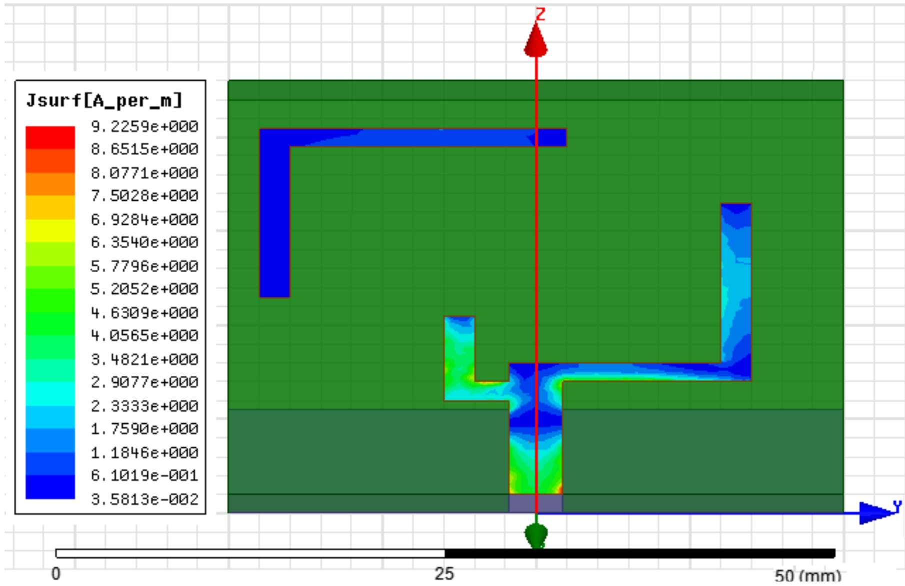


(b)

Figure 7. 40% Radiation fields overlays: (a) at 5.6 GHz; (b) at 2.5 GHz.



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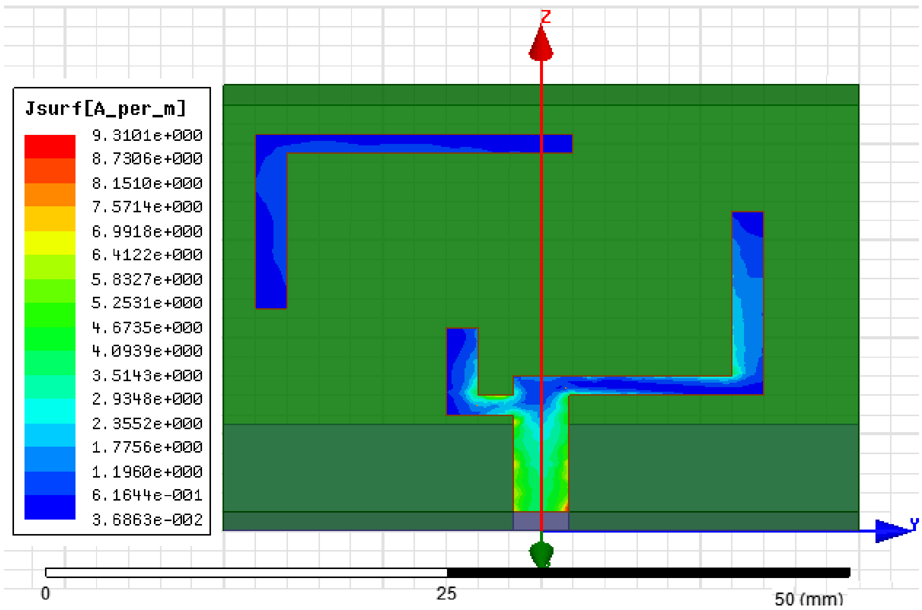


(b)

Figure 8. Surface current distribution: (a) at 5.6 GHz; (b) at 2.5 GHz.

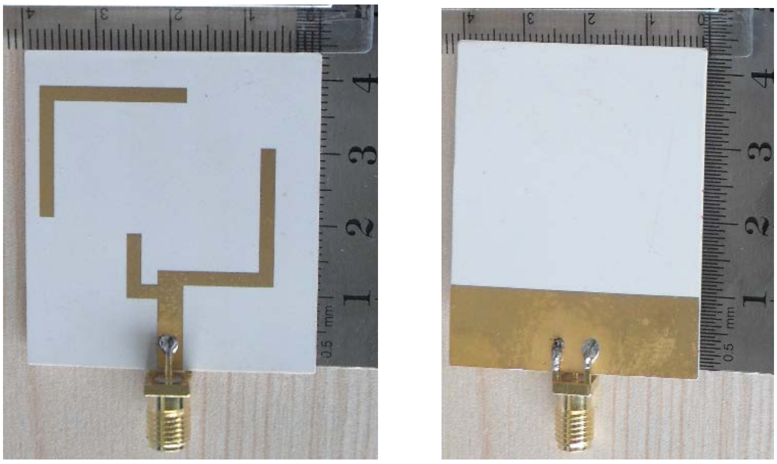
2.4. Manufacturing Results

With the satisfactory simulation results in hands, the antenna design model was manufactured as per pictures in **Figure 9**. The two dimensional (2D) radiation test results for one sample product presented in **Figures 10-12** are coherent with the simulated results.

3. Discussions

Analyzing the simulation RL, the −10 dB bandwidth (BW) approximates to 592 MHz, or 2390 MHz - 2982 MHz in the first frequency band as well as 252 MHz, say 5133 MHz - 7753 MHz in the second band. With these bandwidths, the design qualifies for dual wideband antenna [15].

The antenna mismatch total efficiency is very good in both frequency bands.



(a) (b)

Figure 9. Picture of the manufactured antenna: (a) top view; (b) bottom view.

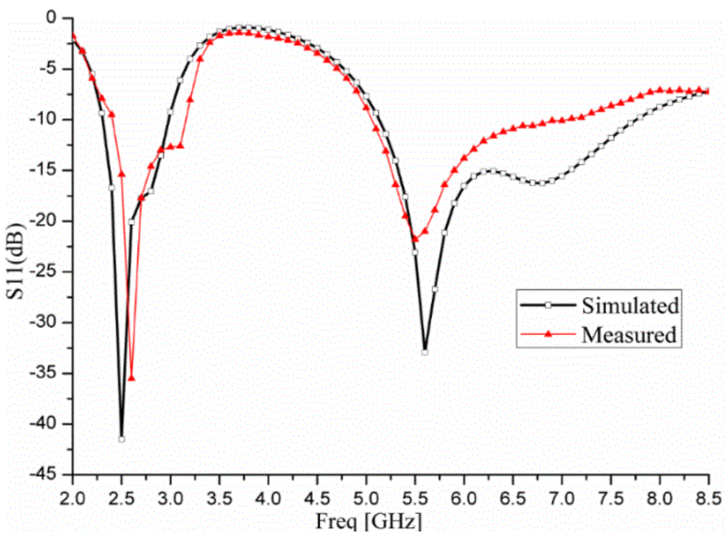


Figure 10. Simulated versus measured RL.

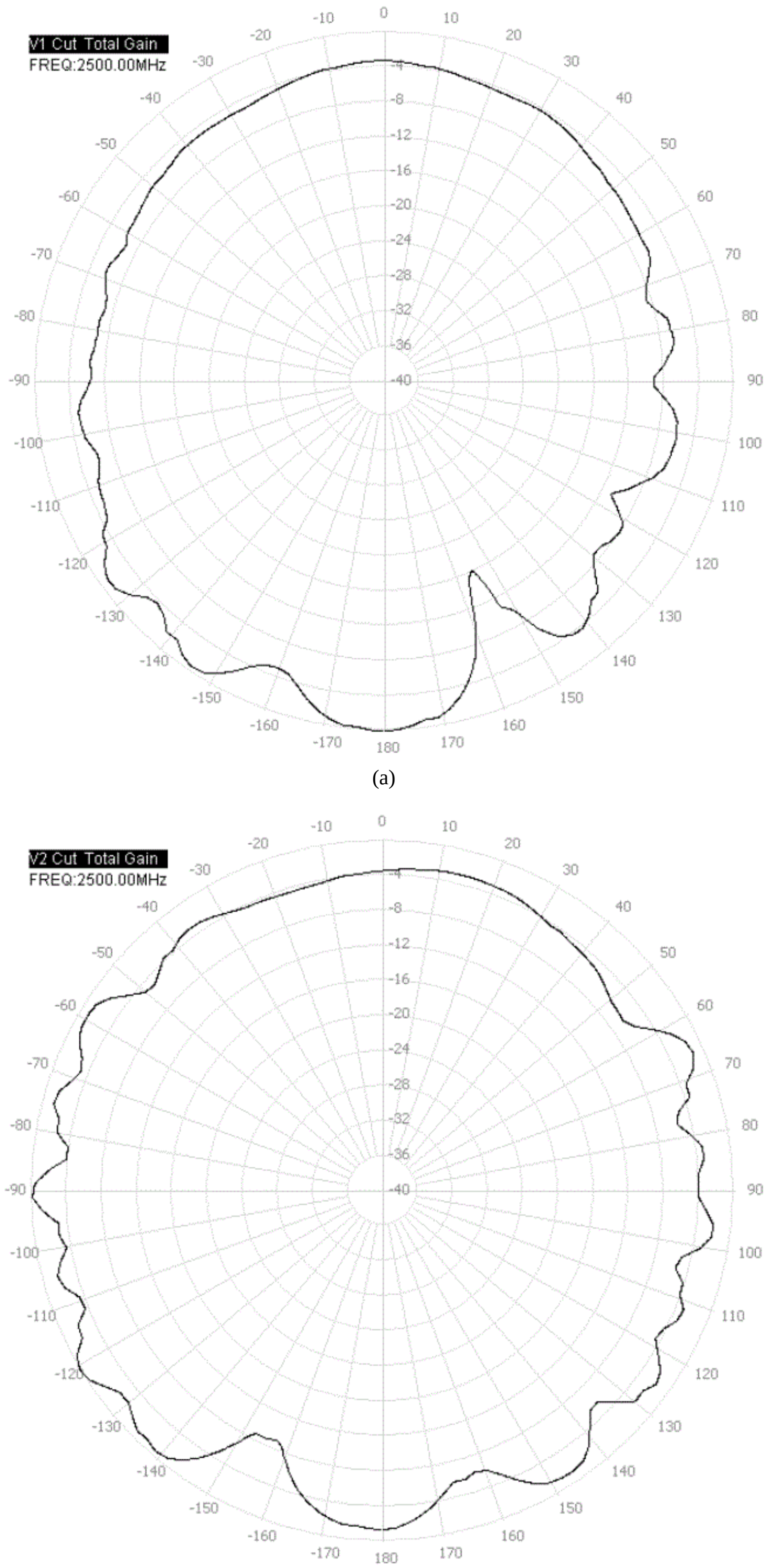
Looking at the measurements results, however, this antenna suffers from losses and signal degradation due to interconnect effects [24], just upon the port welding.

It has been noticed that the port may not be soldered by directly pressing it against the substrate's edge; rather, a small gap would be left or otherwise the radiated power distorts. On the other hand, when the gap in between the port and the substrate edge is slightly increased to about 1mm, the environmental conditions interfere to affect the integrity of the signal transmitted to the antenna.

This antenna is a prototype sample which was not packaged in any commercial product. The encountered signal integrity problems due to port soldering would be carefully solved whenever preparing this antenna for the real applications of a miniature antenna for WiFi and WiMAX systems.

4. Conclusion

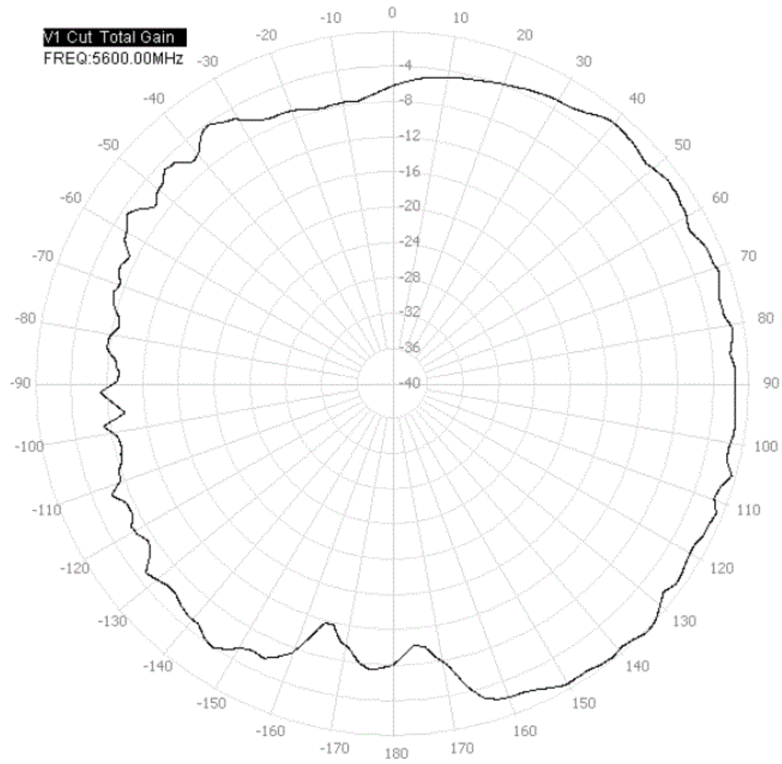
All the pre-set goals have been achieved. The antenna's overall performances were proven by both simulation and manufacturing results. The antenna was manufactured by a competent company while the related measurements were conducted in the University. For the tested three samples, results are all coherent; however, only one sample's 2D measured radiation patterns are presented in this article. The designed, manufactured and tested/



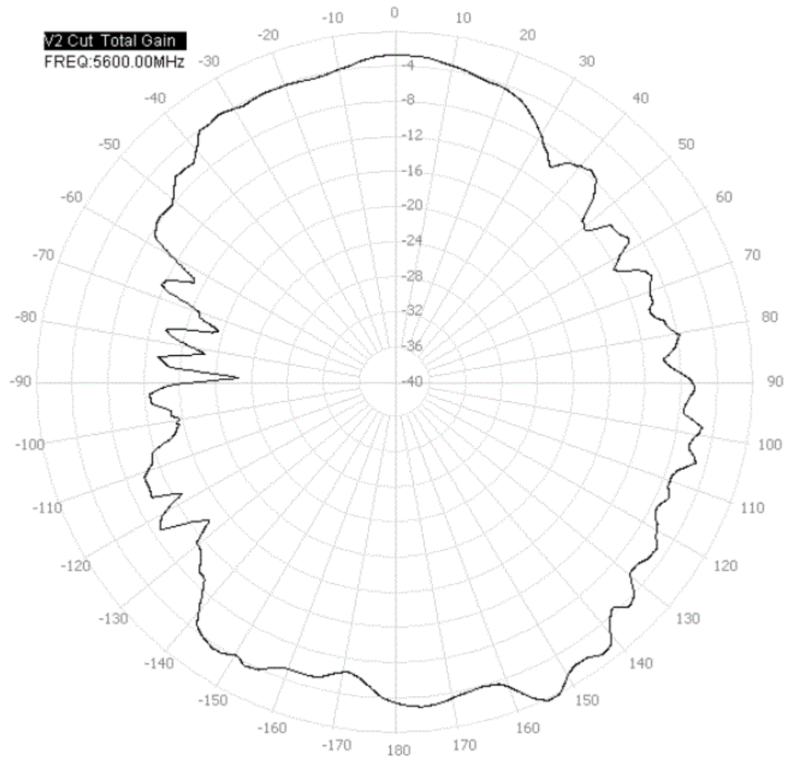
(a)

(b)

Figure 11. Measured 2D Radiation Patterns at 2.5 GHz for one sample product: (a) in horizontal direction; (b) in vertical direction.



(a)



(b)

Figure 12. Measured 2D Radiation Patterns at 5.6 GHz for one sample product: (a) in horizontal direction; (b) in vertical direction.

measured antenna system would be subjected to final product manufacturing, especially when there is any industrial request.

Acknowledgements

A lot of gratitude is addressed to the Government of People's Republic of China, to have supported and strengthened engineering research activities in the University of Science and Technology of China (USTC). Many thanks also go to the University of Rwanda, college of Science and Technology (UR, CST) for a couple of valuable supports.

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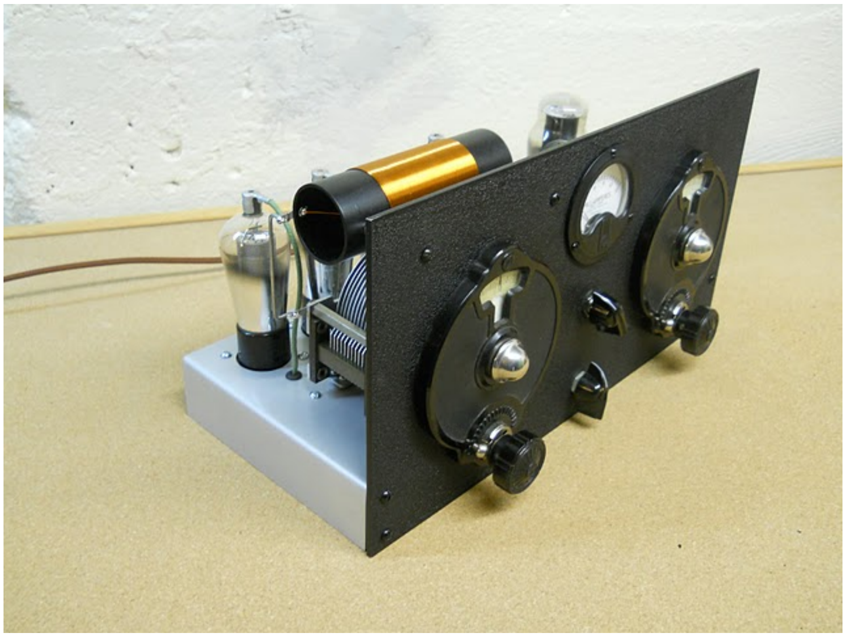
RETROVOLTAGE

Vintage and Modern Technology and More

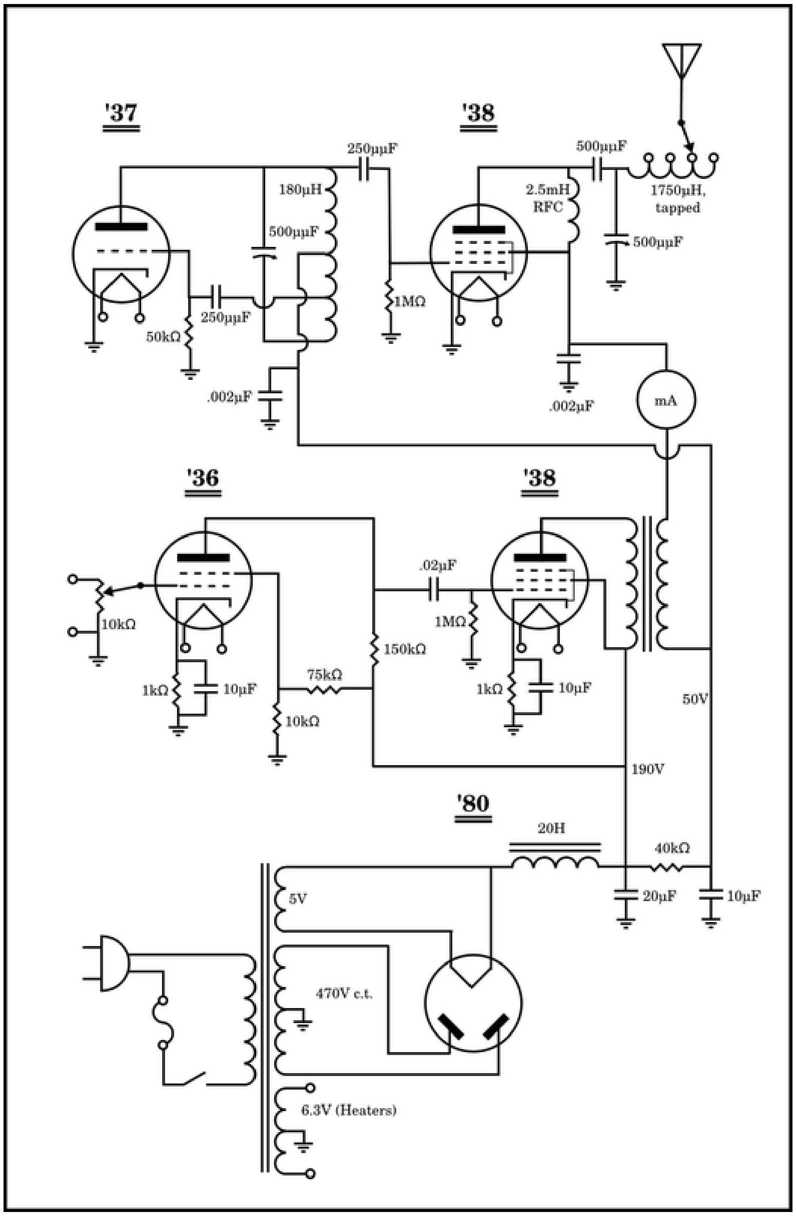
Showcase: Homemade 1930s-Style AM Radio Transmitter

Posted on April 5, 2011

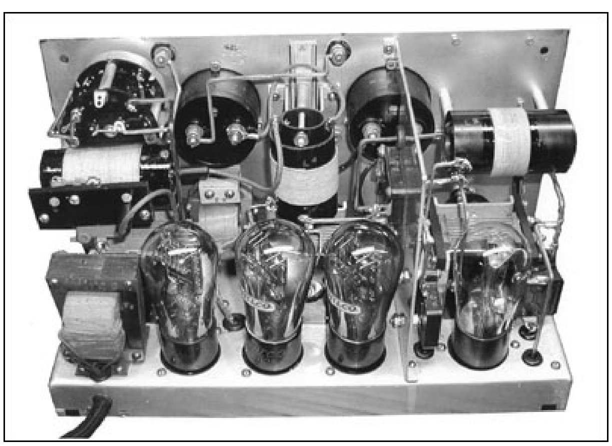
Fellow radio hobbyist Jon the Grimm built this beautiful "homebrew" AM transmitter using tube technology, in the style of an original 1930s radio transmitter. Operating under Part 15 regulations, his transmitter has achieved a short range – perfect for feeding modern music to antique radios that might not otherwise have a way to receive programming without interfering with your neighbors reception.



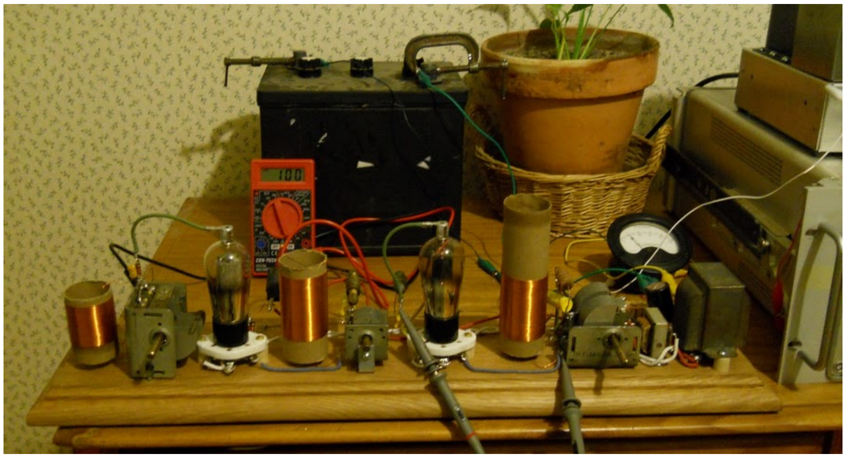
Built using period-correct enclosures and wiring techniques, this 5-tube transmitter uses the aesthetically pleasing "globe" style of vacuum tubes: #36, 37, 38, 38, 80 according to this schematic:

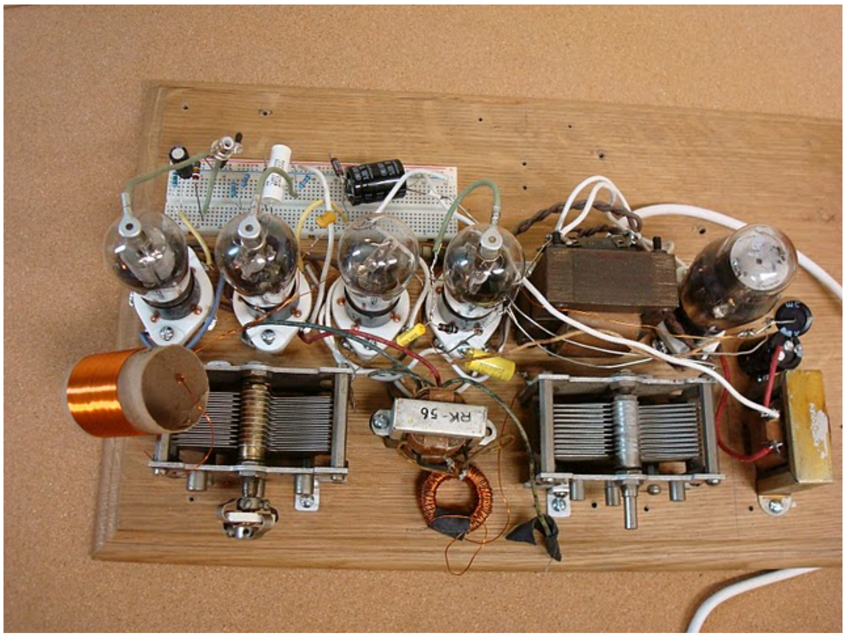


His inspiration came from this photo of an original 1930s-era miniature AM transmitter:



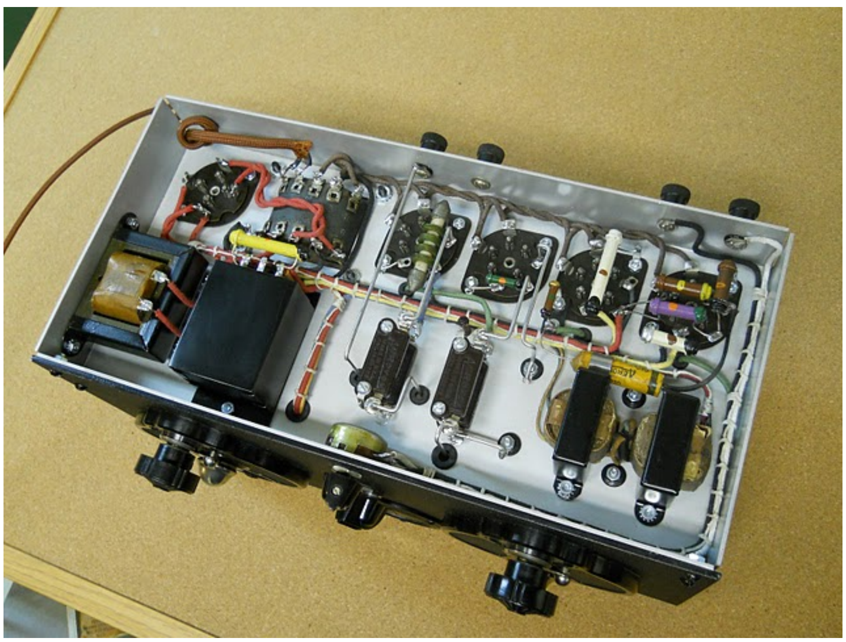
Jon posted some design photos in the [thread](#) at the Antique Radio Forums, which I'm sharing here. You can see the design take shape, from the initial circuit prototyping, to the full breadboard, to the final product. I especially like paper towel/toilet paper tubes being used as coil forms.

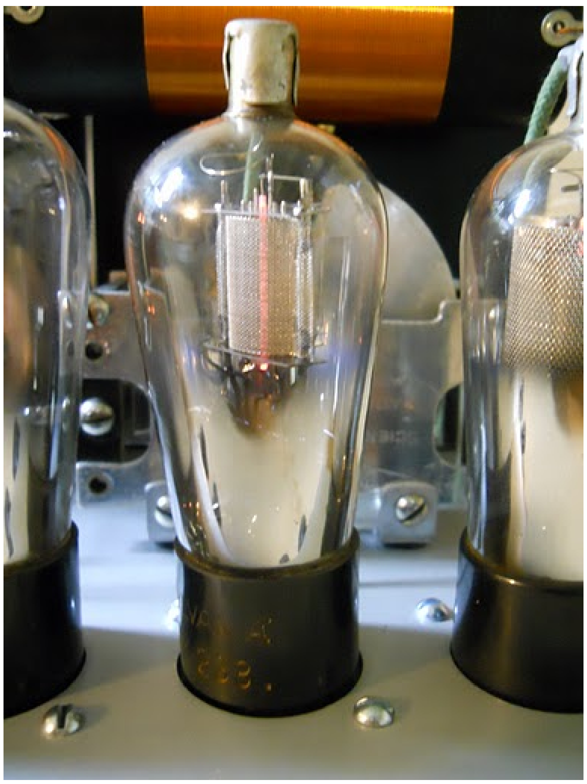


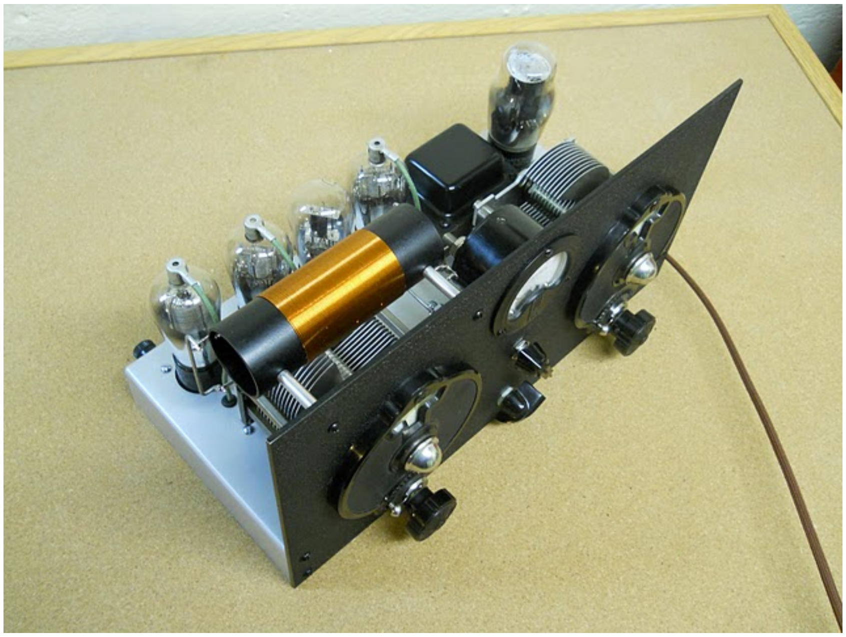


It’s a functional work of art. If I didn’t see the construction photos, I’d swear it was actually from the 1930s. Some more views, note the attention to detail with the wire lacing.


MILLIAMPERES







And with the last touch, correct power and switch knobs:

Jon doesn't have a web site, but I thought his work deserved some recognition. This is a stunning piece of engineering, using period-correct pieces combined with a modern eye for engineering and circuit design. Not to mention it's just beautiful. You can contact him via the [Antique Radio Forums] if you have any questions for him about the build process.

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This entry was posted in Collections, Commentary, Radios and Tubes and tagged 1930s, am radio, globe tubes, homebrew, Part 15, transmitter, vacuum tube. Bookmark the permalink.

6 Responses to *Showcase: Homemade 1930s-Style AM Radio Transmitter*

Ken K *says:*

June 17, 2015 at 8:54 am

How about a parts list and supplier list along with tube types and resistor, capacitor ect, ID numbers so the rest of us can acquire parts to build this type radio transmitter ?

Reply

jwk *says:*

June 17, 2015 at 10:12 am

You should be able to get most of that info from the schematic. The tube numbers (36 37 37 38 80), R and C values, transformer voltages, and inductances in H of the chokes and coils is given.

You'd be on your own for winding the coils and picking out an okay modulation transformer (to the right of the lower '38 tube) though.

You should be able to get most resistors from Mouser or Digikey; Angela Electronics will sell you sockets, and you'd probably want to check eBay for variable capacitors and panel meters like that.

Reply

Jack *says:*

March 7, 2015 at 7:36 am

Hi, great info! I've updated my QRP website, I'm sure it's of interest to fellow shortwave radio enthusiasts.

Here's the link: http://www.stationqrp.com

73's
Jack

Reply

---

carey *says:*

May 13, 2013 at 9:17 pm

You have to give a tube radio at least 20 to 30 minutes just to warm up and then you decide what frequency you want to be on and load the
plate and tune them up. It was an entertaining radio program that played the music people wanted to hear combined with his groovy upbeat personality.

Reply

Kjeld *says:*

June 16, 2012 at 6:51 am

Lovely…just lovely

Reply

Andy UU1CC *says:*

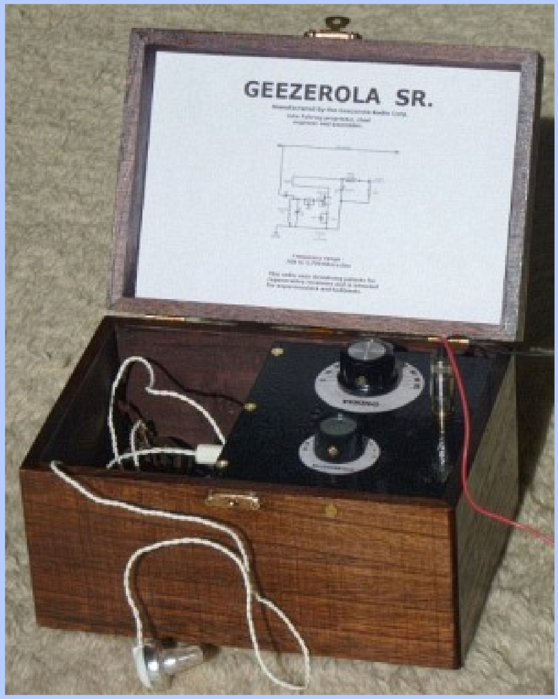
March 10, 2012 at 10:03 am

Super neat radio, I've never seen such AM transmitter replica before. A lot of compliments.

Reply

RETROVOLTAGE

Blog at WordPress.com.



A NICE LOOKING ARMSTRONG REGENERATIVE RADIO

A project from the book "The Old Geezer Electrician"
by John Fuhring

Introduction

I had so much fun and success building the the Armstrong "Crystal" Radio, I thought I'd like to make a nicer looking version and present it in the form of a simple to build kit. The truth is, because my original 1958 regenerative radio and my 2012 version were both so crudely built, I wanted to build something better looking even though it wouldn't necessarily perform any better. You see, I had all these parts left over from the first project and this nice wooden box was on sale for only $2.50, so it really wouldn't cost me much except a little of my time, so why not? Well, I hope you agree, this is a much better looking radio and with its internal compartment, it has plenty of room for a wire antenna, a ground wire, a high impedance earphone and the antenna & ground jack. There's also ample room for a bag of peanuts or a candy bar, but those aren't essential to the operation of the radio.

Although this little radio performs very well with an antenna only a fraction as long as what you need for a crystal radio and it is as easy to build as even the most simple crystal radio, it has an amazing ability to pull in stations and can separate stations that are quite close to each other on the dial that no crystal radio can come close to matching. In other words, this little radio has excellent sensitivity and selectivity which have always been the outstanding characteristics of an Armstrong regenerative radio. On a small scale, this little radio is meant to resemble the Aeriola Senior, the very first Armstrong regenerative radio to be sold to the public in 1921 and so I'm calling my little radio the Geezerola Senior.

What is in a name?

Putting on the "brand name" is optional, in fact, you can call it anything you wish. The name "Geezerola" is a play on the name of the very first one-tube Armstrong regenerative radio to hit the market (in 1921). This radio

was called the Aeriola Senior and it was manufactured by Westinghouse for a newly formed company called RCA (the Radio Corporation of America). RCA, through their system of patents on just about every kind of radio circuit, was to dominate radio design for the next 40 years.

Just a little history here: the first commercial broadcast was made by station KDKA on November 2nd, 1920 at 8 PM and it featured the returns from that year's Presidential election. It is estimated that less than 1,000 people had radios and were able to hear that famous broadcast, but it caused an absolute sensation and the news quickly spread across the nation by word of mouth, telephone, telegraph and newspaper about this wonderful new technology. Just a few months after this broadcast, the Aeriola Jr. and the Aeriola Sr. went on sale and were eagerly bought up by the public who wanted a radio regardless of the price. In its day, this new radio technology caused a much, much bigger sensation than any new iphone or ipad announcement.

The Aeriola Senior radio from 1921.
This Armstrong regenerative radio in a box is what inspired me to create the Geezerola Senior.

The similarities between the Aeriola and the Geezerola

My version of Armstrong's regenerative radio is functionally identical to the Aeriola Senior except the Geezerola uses a tiny triode FET rather than a large WD-11 triode tube. Both the tube and the FET pass electrons through their structure and both regulates that flow of electrons by means of a tiny electric field. Both radios use a tickler coil and both use a throttle to control the amount of regeneration. They both require high impedance headphones (or earphone) for listening.

In terms of performance, my Geezerola Senior operates and sounds identically to the tube type regenerative radio I built in 1958. Finally, both radios were designed to operate with similar band coverage on the old AM broadcast band.

The differences between the Aeriola and the Geezerola

The Aeriola uses a large glass vacuum tube (a WD-11) as its amplifying device. To create free electrons inside the tube, the WD-11's cathode must be heated to red hot by a large current supplied by an

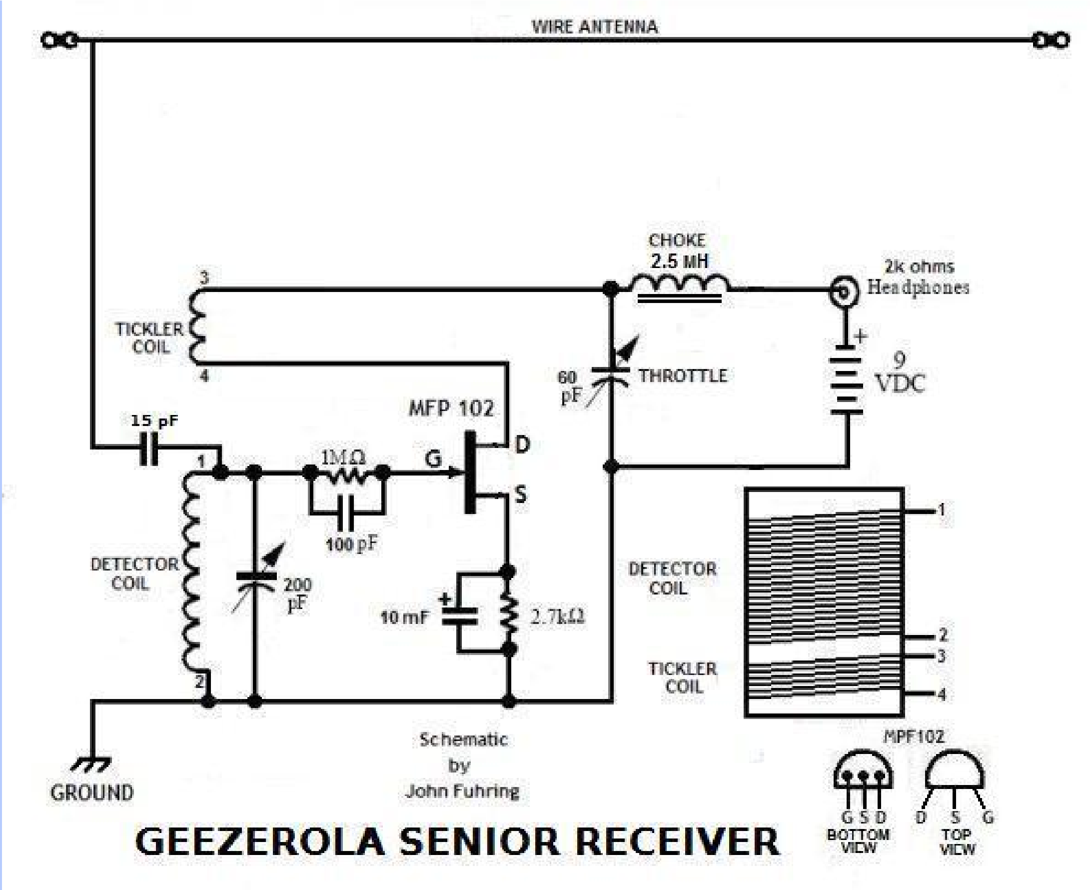
external 'A' battery (which had a short life and were always going dead). Since the silicone crystal in the FET of the Geezerola does not require heat to create free electrons, it does not need an 'A' battery.

To cause electrons to actually flow through the WD-11 tube (and other circuit elements, including the headphones), a second 22 1/2 volt external battery, the 'B' battery, must be connected. The terminals on the left of the radio are for battery connections (and for headphones and a ground connection). The FET also must have a battery to cause electrons to flow through it, but it operates quite nicely at a much lower 9 volts. Because it its so tiny and it lasts so long, the Geezerola's 'B' battery mounts internally and is hidden under the wooden chassis.

Perhaps the major difference between the two radios is the fact that the Aeriola uses very bulky variable inductors (called variometers) for tuning and throttling rather than the tiny and very inexpensive variable capacitors used in the Geezerola. Many years ago variometers were cheaper and easier to make than variable capacitors, but today almost nobody uses them. Of course, the much larger WD-11 tube, the bulky variometers and other large elements in the Aeriola make its overall size much, much larger than the Geezerola.

The biggest difference was that the Aeriola cost the average worker a full THREE WEEKS PAY to buy while my radio can be built for just a couple of hours pay, even if you are earning minimum wages.

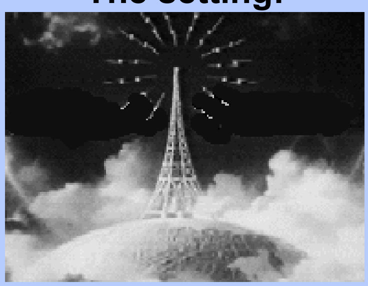
The electronic principles on which this radio operates



The Geezerola radio schematic diagram.

You may want to use this diagram as a reference as the operation of the radio is explained below

The setting:



Imagine that there is a radio station 10 miles away and that it that is broadcasting radio waves at 1,400 KHz.

Imagine that our radio station is broadcasting hundreds of watts of energy into space, but because of the laws of physics, the vast majority of that energy is lost to space. Imagine that we could somehow capture just a tiny amount of this energy with an antenna. Imagine sending this tiny amount of energy to some kind of a circuit where it would be amplified so that we could hear what is being broadcasted even if we were miles, maybe even hundreds of miles away. Imagine that we have a simple radio like the one above connected to a wire antenna.

(1) The passing radio wave from our station induces a tiny high frequency voltage on our antenna wire.
.

(2) The high frequency voltage from the antenna is lightly coupled (by a 15 pF capacitor) to a tuned circuit consisting of the detector coil and its variable capacitor (seen to its right) called the detector tuning capacitor. The combination of the detector coil and the tuning capacitor is called a 'tank circuit' because it

can be thought of as holding a signal like a tank holds water.
.

(3) By carefully adjusting the 0-200 pF detector tuning capacitor, the tank circuit will be right in tune with 1,400 KHz and a tiny 1,400 KHz alternating voltage (called the signal) will appear across the tank circuit circuit.
.

(4) The tiny signal from the tank circuit is coupled to the gate (G) of the FET by the 1 megohm resistor and 100 pF capacitor combination called the 'gate tickler' network. The small signal at the gate of the FET causes relatively large changes in the high frequency current flow between the source (S) and drain (D) in the FET.
.

(5) This high frequency current is wired to flow in the 'tickler coil' and it will produce its own magnetic field in the tickler coil. This magnetic field is close to the detector coil which picks it up and creates a 1,400 KHz voltage that adds to the original 1,400 KHz voltage from the antenna thereby amplifying the original signal.
.

(6) This operation occurs over and over again so that the original signal is amplified hundreds of times. The way the original signal is amplified by being fed back on itself for more amplification is called 'regeneration' and the amount of regeneration (also called feedback) must be carefully controlled or it gets out of hand and the radio squeals.
.

(7) Another advantage of feeding a signal back on itself is that the sharpness of tuning (called 'selectivity') is multiplied each time the signal goes through regeneration. This means that a simple tank circuit such as we have now is able to separate out a close by station so that it doesn't blend with the station we want to listen to. Crystal radios with one or two or even more tuned circuits can't achieve this kind of selectivity.
.

(8) The control of high frequency current flow in the tickler coil is what controls the amount of regeneration and it is the job of the 'throttle capacitor' to throttle or control the amount of regeneration so that the regeneration doesn't get out of control. When the throttle is set just right, just before the circuit goes into runaway oscillation, the amplification of weak signals is at maximum and so is the selectivity of the radio. In many cases it is kind of amazing how nearby stations "disappear" as the regeneration is throttled up.
.

(9) It should be realized that the 1,400 KHz AM radio signal consists of a strong "carrier wave" (that never varies in frequency), but it also consists of two "sidebands" that carry the voice or music. The strength and distance from the carrier wave of these sidebands is what a radio detector responds to when it creates music or voice audio from the AM signal.
.

(10) While the AM signal is being strengthened by regeneration, the carrier wave and the sidebands mix to create an audio "heterodyne." Audio heterodyning occurs when different frequencies mix to produce a third subtraction frequency. For example, if a 1,400 KHz carrier wave mixes with a 1,401 KHz sideband, it will produce a 1 KHz tone. Since voice or music is simply a series of rapidly changing tones, mixing like this will produce our sound.
.

(11) The audio signal produced by heterodyning the carrier wave with the sidebands causes the current flowing through the FET to vary just as the radio frequency waves (that we can't hear) cause the current to vary, but this current varies at a relatively slow rate that the human ear can hear. It is these variations in the current through this circuit that our magnetic earphones respond to to make sound waves.
.

Building the radio

To house my project, I decided to put it in a wooden box. An attempt make a box from scratch would require skills, materials, tools, money and time, but for only a few dollars, it is so much better to just go out and buy something. The box I selected is 7 1/4 inches wide, 5 inches long and 4 inches tall. Inside, with the lid open, it is 6 3/4 wide, 4 7/16 long and 3 inches deep. Actually, the box is considerably wider than necessary, but this allows for a large storage compartment that is extremely useful. The only critical dimension is the depth. If you use a toilet paper roll as a coil form, your chassis can be no less than 3 inches deep. A more compact coil will allow for smaller dimensions. These little boxes are made out of basswood (linden wood) that is white, but stains nicely and they come with all the hardware including a latch and hinges.

For the wooden chassis and top deck, I bought a long strip of 1/4 inch birch plywood that I carefully cut to size with a hacksaw. When I had cut out the pieces I needed, I drilled holes and countersunk areas in them as necessary. When I had the pieces I needed, I screwed them into an 'L' shaped bracket (as shown), but did not glue the bracket together until I was finished with the countersinking and the mounting of most of the components. After I had mounted the battery, coil, variable capacitors, RCA and phone jacks, driven the three nails through from the top and soldered in the FET, I put down a thin layer of glue and screwed the two panels together. After the glue had set, I installed and soldered in all the other parts and connections as will be described shortly.

If you decide to build this radio, here is what you will need:

1) A wooden box you can get at an art store. Be sure it is at least 3 inches deep.
2) A 1/4 inch thick wooden chassis board you will need to cut and fit into an 'L' shaped bracket.
3) A large knob for the main tuning.
4) A smaller knob for the throttle.
5) A paper toilet roll for the coil form.
6) 10 feet of 30 Ga. magnet wire.
7) A few inches of 18 Ga. insulated wire.
8) An MPF-102 (or similar) FET transistor.
9) Two plastic variable capacitors (60 pF & 140 pF dual units) with shaft extensions from Scott's Crystal Radios.
10) A 2.5 mH choke coil. Tiny, low current chokes work great. Check e-bay.
11) A 10 MFD, 16WVDC electrolytic capacitor for the source bias network. Anything over 1 MFD will work fine.
12) A 2.7 K ohm resistor, 1/8 watt or larger for the source bias network.
13) A 100 pF capacitor (50 volts or greater) for the gate tickler circuit.
14) A 1 megohm resistor for the gate tickler circuit.
15) A 15 pF capacitor (1KV) to couple the antenna to the tuned circuit.
16) A 3.5 mm, non shorting, monophonic phone jack
17) A 9 volt battery
18) A battery holder
19) Seven ea. 1/2 inch brass wood screws
20) Three brass plated nails
21) A RCA jack.
22) A RCA plug with an antenna wire and a ground wire soldered on and with the wires terminated by two alligator clips. It is suggested that a red colored wire be used for the antenna and a black colored wire be used for the ground, but the color choice is yours.
23) Philmore sells a rugged and very inexpensive 2,000 ohm earphone that works quite well. "Crystal" type piezoelectric headphones or earpieces work too but you must place a 2,000 ohm resistor across them or they won't pass enough current. Headphones as low as 600 ohms work very well.

Getting down to brass tacks

From the pictures, you can see that I hammered three brass plated nails clear through the top wooden board to provide points to mount the three FET leads. By looking at the photos below, you can see how things are mounted on the top and side decks.

You will notice that I am using two small variable capacitors and they each consist of dual elements. One element is 60 pF and the other is 140 pF so that if I bus them together, I get 0 to 200 pF of tuning range. This is exactly what I do for the station tuning capacitor. For the throttle, I use only the 60 pF part of the capacitor, and leave the other element unused. With about 10 turns on the tickler, 60 pF is plenty of bypass to cause regeneration even at the lowest frequencies.

If you use the same tuning capacitors from the same supplier, you should also order extension shafts. Unfortunately, these capacitors do not come with mounting screws and that can be a real problem, but in this case I took small drops of wood glue and glued the capacitors in. This works great and because the 1/4 inch shafts are quite long and so they easily extend through my relatively thick (1/4 inch) wooden front panel. If you decide to use a metal panel to mount your controls, you might have to buy some small screws for the capacitors and mount them that way. If the shafts are too long for you, you may want to do as I did and shorten them, but you will have to shorten their long mounting screws too.

Mounting my phone jack in the thick wood of my side panel was a bit of a problem because it was too thick for the jack to stick through. I picked a spot I where wanted the jack to be then carefully thinned the thickness of the

wood by countersinking an area with a grinding tool and a small diameter flat faced grindstone. When the wood was thin enough (about 1/8 inch thick), I made the hole big enough to accommodate the jack, pushed the jack through and screwed on the nut that holds it in. One side of the jack is connected to the + side of the battery and the other side has the 2.5 MH choke coil soldered to it as shown in the picture. It all works great. By the way, this is also the ON/OFF switch for my little radio. When the phones or earpiece is plugged in, current flows and the radio is on, but when I unplug the phones, no current can flow and the radio is off. Isn't that clever?

To mount the RCA jack for the antenna and ground connections, I countersunk into the thick wooden panel in the exact manner described above. I made the wood below the panel thin enough and the hole wide enough to accommodate the jack, its mounting nut and ground lug washer.

I used a toilet roll for the coil form. Toilet rolls are still made of the same flimsy paper that must be soaked in a dope of some kind to make them stiff and so they won't fall apart. The next paragraph tells you the length of my main and tickler windings, but you should know that for small diameter paper rolls, you will have to use slightly more wire and thus more turns to get the same inductance.

To make the tuning coil, I took an ordinary toilet paper roll and soaked the first 2 1/2 inches with a liquid dope. I let the dope soak through the paper and after it hardened, I carefully sawed two inches off the doped end of the paper roll. A 1/4 inch from an end of the tube, I drilled two tiny holes next to each other and then drilled two more tiny holes 0.9 inches down the tube from them. I threaded the No. 30 wire through the first two holes so it was secure and wouldn't pull out and began to wind the tuning coil while keeping the wire taught at all times. When I figured that the coil was long enough, I put my thumb on the coil to keep it from coming undone, cut the wire and then threaded the end through the two little holes. I spread a thin layer of fast drying dope on the coil to stabilize it and help with the final trimming operations.

As is recommended in all coil making of this sort, I made the coil too long at first so that I could later bring it into the proper tuning range by taking off some turns. Not all is lost if you make your coil too short because you can "splice" on some more 30 wire and add a few more turns, but it is so much easier if your coil is too long to begin with. By "cutting and trying" I finally ended up with was a coil that was 0.820 inches long. No, I didn't bother to count windings, but there was something like 80 altogether, but please remember, your coil will vary depending on the diameter of your coil form -- a thiner coil will require more turns and if your coil form is really small, there is nothing wrong with wrapping turns over other turns.

The old "cut and try" method electricians have been using for over 100 years

This is something you will have to experiment with. Start with a coil with plenty of turns and if your radio won't tune high enough, simply remove a few turns and try it. It really helps if you have a local station at the top of the dial. You may have to repeat this step three or four times until your radio tunes high enough. As I've already mentioned, I can't give you the exact number of turns you will need to remove because toilet rolls vary. You will have to "cut and try" to get the right number of turns.

To make the tickler coil, I drilled similar small holes side by side, threaded No. 30 wire through them and wrapped about a 10 turns on the roll. If you put too many turns on the tickler coil, you may not be able to throttle down enough to stop oscillation up at the high end of the tuning range, throttling won't be smooth and you won't be able to achieve maximum sensitivity on weak stations. I suggest having just enough turns on the tickler so that you begin to hear weak stations squealing when the throttle is between '3' and '4' and the tuning dial is near the top (100). If squealing on weak stations starts at some point less than 3.5, keep taking a turn off the tickler until the squealing starts where it should. Before you are done, check for squealing on the bottom of the tuning dial. Squealing should start at about '7' or '8' on the throttle, but if it doesn't, you've taken a turn too many off and will have to splice enough wire to the coil to add a turn or two. Again, this is the old "cut and try" method so dear to the hearts of experimenters and it's easier than it sounds.

Although I will supply a lot of building detail, there are a lot of things you will have to figure out. A lot of fun and satisfaction comes from figuring these things out for yourself.

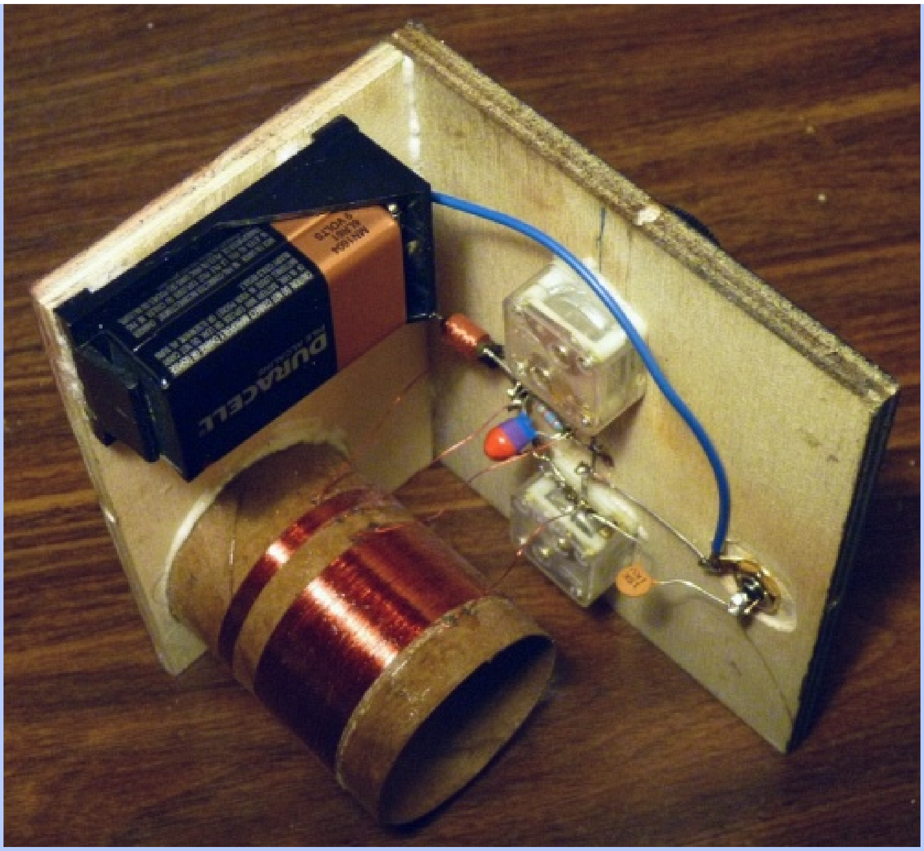
Tools you will need:

1) Drill and bits
2) Round file for enlarging holes
3) Screwdrivers to fit the screws you will be using
4) Ruler

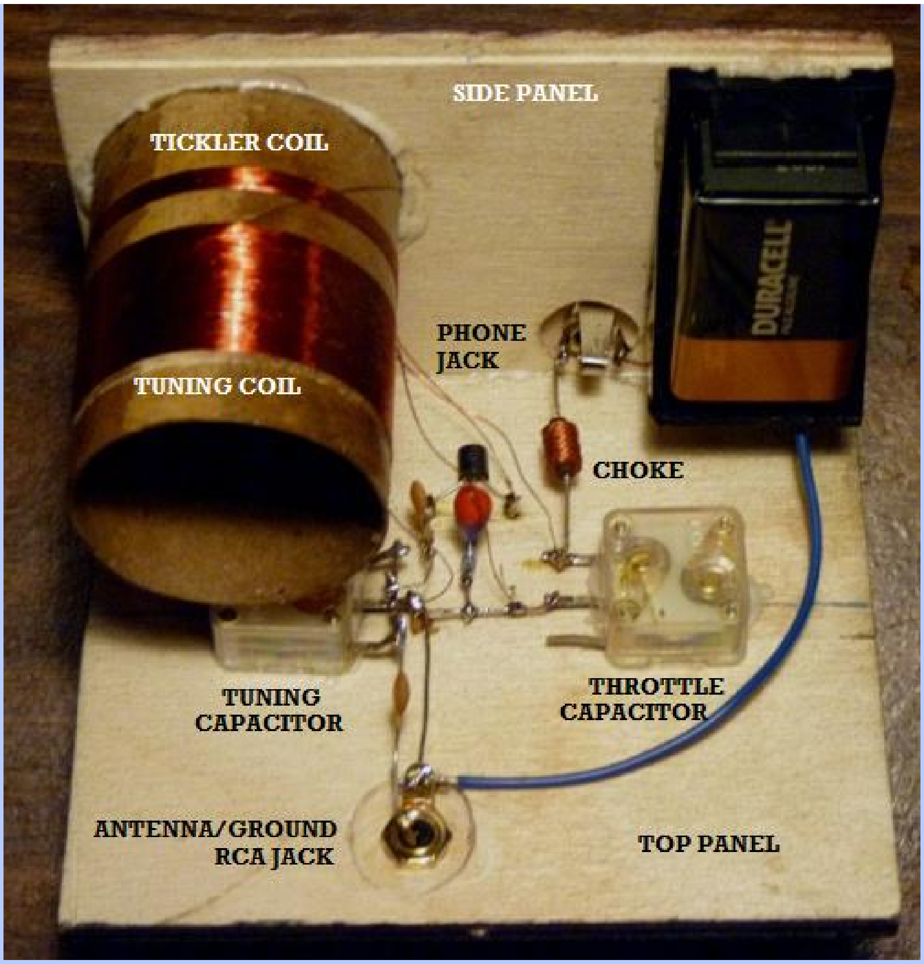
5) Small hammer
6) Small saw
7) A low wattage soldering iron with a sharp tip.
8) Electronics grade (rosin core) solder. Having a jar of extra flux is really nice.
9) Needle nose pliers. I really love using hemostats for doing fine work.
10) A "Dremel" type grinding tool if your panel is thick and you need to counter-sink the phone jack.

Suggest layout and building instructions.

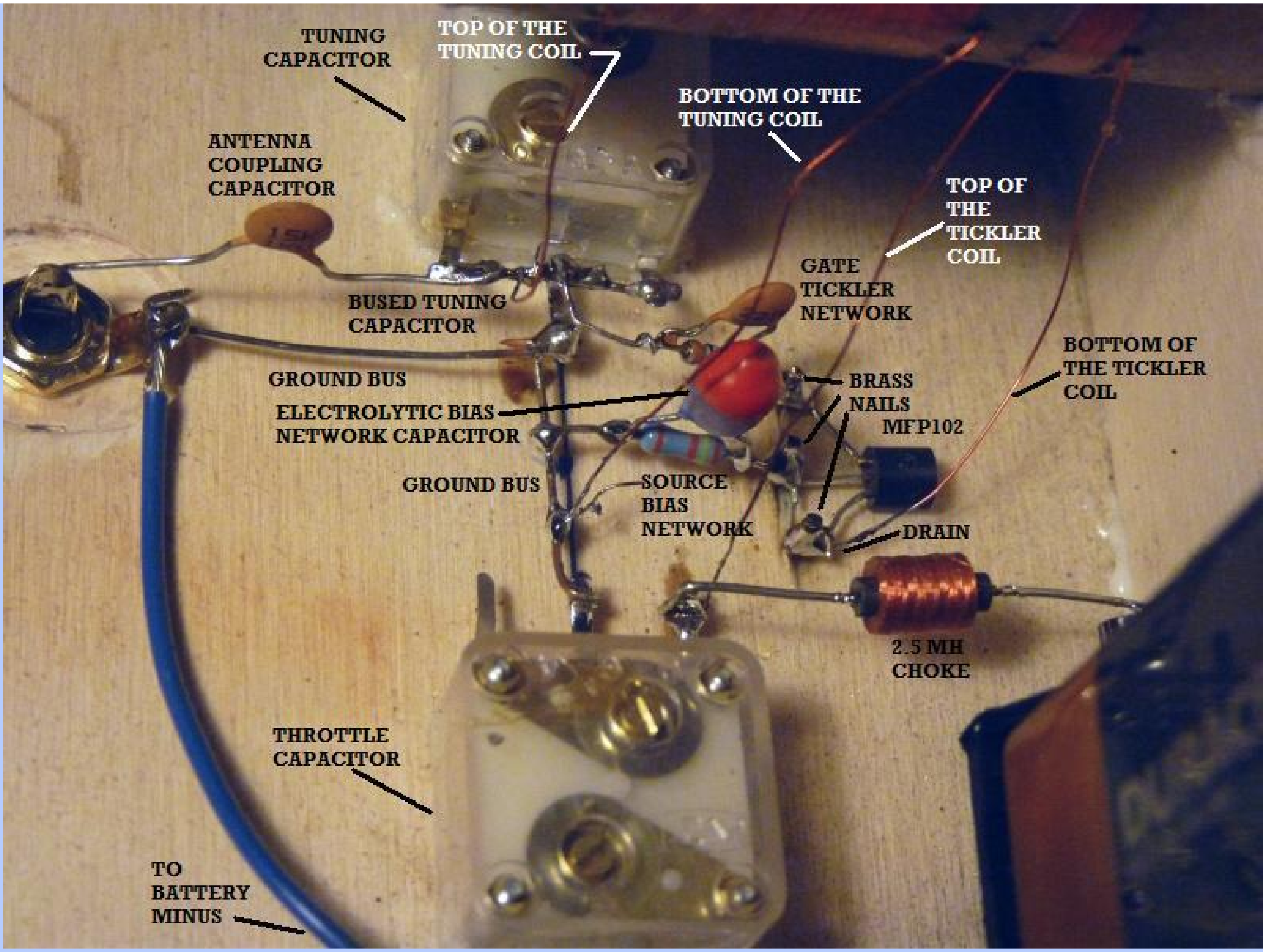
The top panel was cut to fit the box and then painted black.
A second side panel was cut and screwed to the top at a 90 degree angle to make a wooden chassis.



A view of the underside of the wooden chassis.
The battery holder, the phone jack and the coil form
are mounted on the side panel. All other components
are mounted on the top panel.



A view with the top panel on the bottom and the side panel on top. Note how the phone and the RCA jacks are countersunk to allow their mounting hardware to be used. The tuning capacitor is on the left (under the coil) and both capacitors are held in with tiny drops of glue.



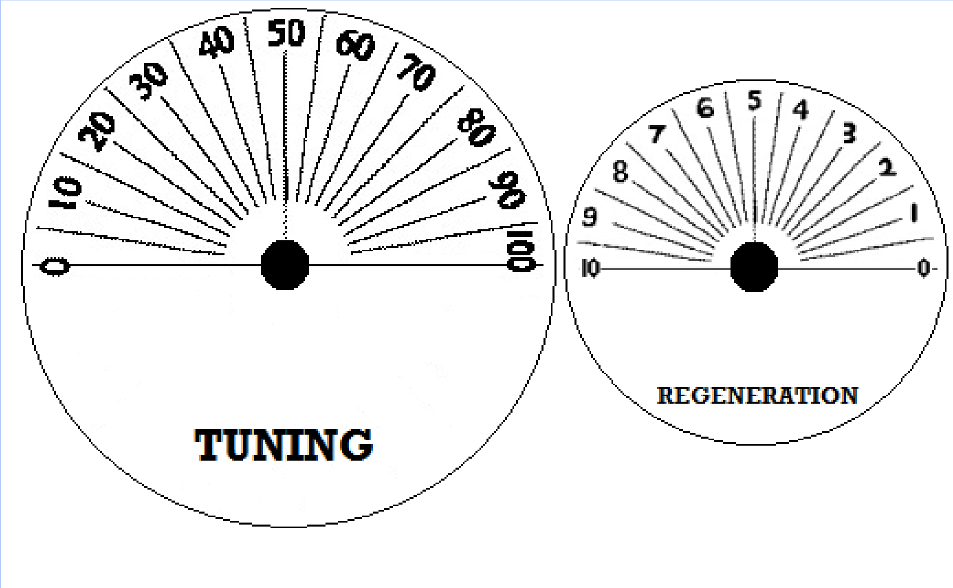
Component layout
Refer to this photo when building the radio.

Detailed assembly

This looks like a lot of work, but the most time consuming part of it is waiting for the glue to dry.

1) Begin by cutting out two wooden sheets to fit the box. The top deck sheet will be painted black after the nails are driven but before the components are mounted.
2) From the top side, drive in three brass coated nails clear through the top deck panel to mount the FET as shown. If the ends of the nails are too long, trim with a wire cutter as necessary.
3) Drill holes for the RCA jack and the phone jack and locate them as shown. The wood will be too thick, so counter sink them from the underside as necessary. The 15 pF antenna capacitor and the choke coil will be soldered in later.
4) With the flat side of the FET facing the board, twist the leads around their respective nails and solder in the FET.
5) Paint or stain the wood as you wish and let dry.
6) Glue the throttle and tuning capacitors in place.
7) Install the RCA and phone jacks.
8) Connect a wire from the battery holder positive to the phone jack.
9) Glue the completed coil form to the side panel and let all gluing set up.
10) Connect the center ground tabs of the two variable capacitors together to form a bus.
11) With a piece of bare wire, connect the ground bus to the ground tab of the RCA jack.
12) Solder a length of insulated wire to the negative side of the battery holder.
13) Bend up and bus together the two tabs of the two sections of the tuning capacitor.
14) Solder one end of the 15 PF antenna coupling capacitor to the RCA jack center and the other end to the bus that connects the two sections of the tuning capacitor.

15) Make up the "gate tickler" network by soldering a 100 PF capacitor across a 1 Megohm resistor (1/4 watt or smaller).
16) Solder one end of the gate tickler network to the gate nail of the FET and the other end to the bus that connects the two sections of the tuning capacitor.
17) Make up the biasing network by soldering a 10 mF electrolytic cap across a 2.7 kilohm resistor (1/4 watt or smaller).
18) With the positive side of the electrolytic capacitor facing the source nail of the FET, solder it to the nail. Solder the other end of the biasing network to the ground bus.
19) Glue the two chassis boards together to form an 'L' shaped bracket. Wood screws may be used to hold the pieces together while the glue sets. Allow time for the glue to set.
20) From tab on the throttle capacitor, solder on one end of the 2.5 MH choke coil with the other end soldered to the empty lug on the phone jack.
21) Solder the insulated wire (connected to the negative side of the battery holder) to the RCA jack's ground lug.
22) Scrape off the insulation and solder the top of the tuning coil to the bus that connects the two sections of the tuning capacitor.
23) Scrape off the insulation and solder the bottom of the tuning coil to the ground bus.
24) Scrape off the insulation and solder the top of the tickler coil to the tab on the throttle capacitor that the choke is soldered to.
25) Scrape off the insulation and solder the bottom of the tickler coil to the FET's drain nail.
26) Carefully compare your work to the photos above. Inspect all soldering and connections and confirm that all is correct.
27) Insert a RCA plug made up with an antenna and ground wire in the jack on the top panel. Connect the antenna lead to an antenna and the ground lead to a good ground.
28) Install the 9 volt battery in its holder.
29) Insert your earphone or headphone plug in the phone plug and adjust your tuning and throttle capacitors until you hear a station.
30) Insure that you can tune stations you know are at the top of the broadcast band. You may have to remove turns from the tuning coil to bring your radio into the proper tuning range.
31) When your radio is working and the tuning range is correct, mount the wooden chassis in the box with brass wood screws. Be very careful to locate the holes in the box so the screws correctly line up with the 1/4 inch thickness of the chassis.
32) Print out the dials shown below, cut them out and soak them with clear varnish. Punch out the center holes and mount them on the top deck of your radio.

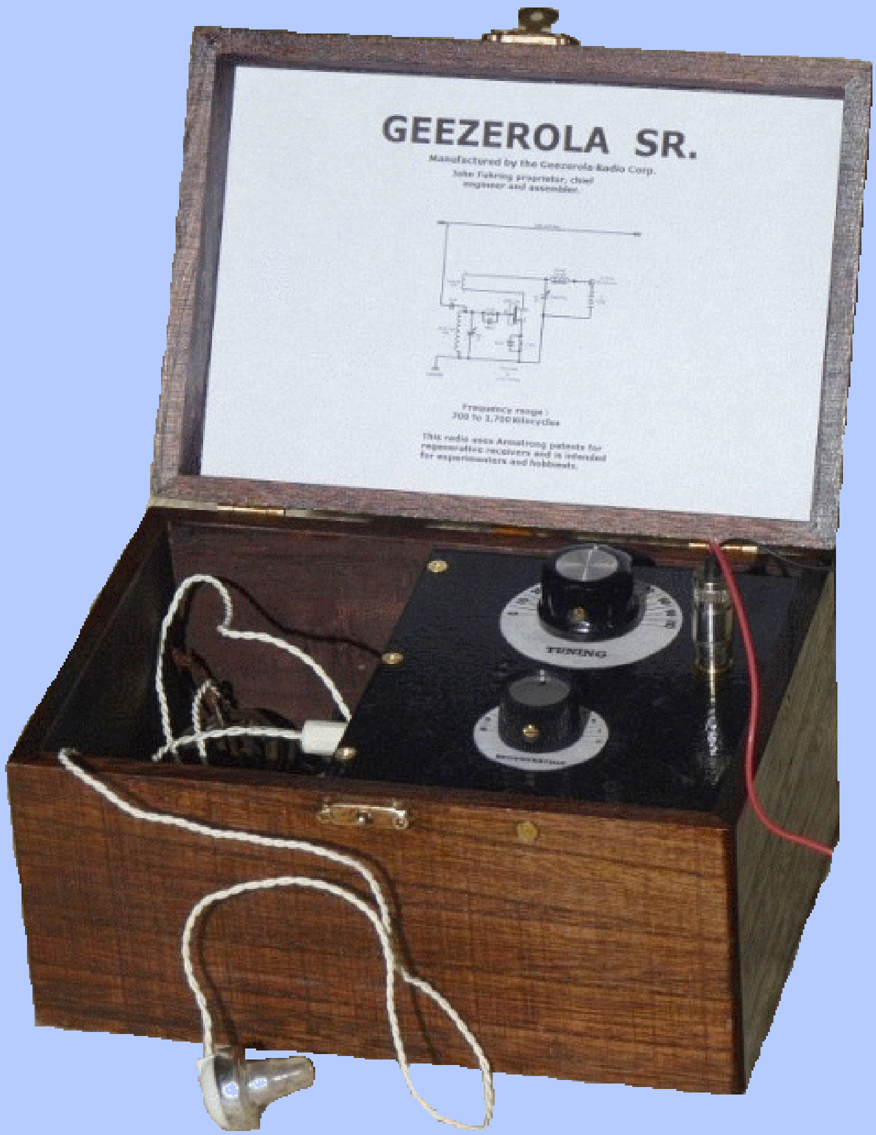


For dial markers, I created this image that may be printed out for a overall width of 3.2 inches or whatever size you find most useful.

By the way, I had a problem with one of the tiny variable capacitors. When I first applied power to the set, the tuning knob worked fine at the top end of the dial, but at mid-dial, the operation of the radio was very unstable

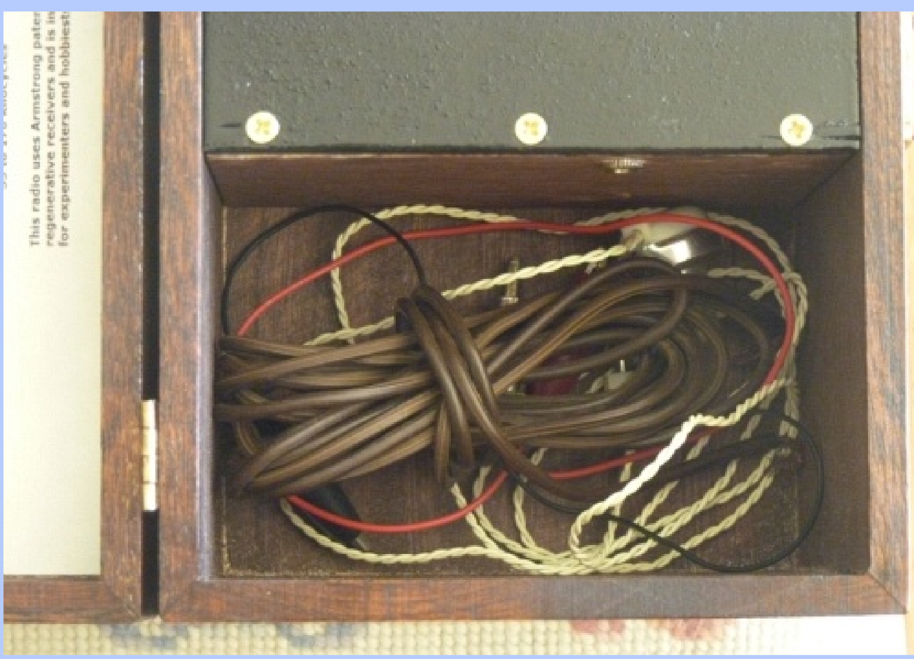
and the knob felt strange as I turned it. It seemed to be mechanical fault inside the capacitor, so I carefully pried the unit off the board, breaking the glue bond. I then carefully pried off the outer clear plastic shell and exposed the four tiny hex nuts in the rear of the capacitor. I carefully removed the hex nuts and started taking the capacitor apart. These capacitors are of a very simple design and come apart very neatly and easily, but everything is very tiny. Well, right away I could see that the brass nut that holds in the center shaft was loose, so I tightened it and then reassembled the capacitor. That did the trick and now everything works perfectly. These little devices are very nicely made for something so inexpensive, but perhaps the factory assembly and inspection isn't exactly aerospace quality. If you have a capacitor that is acting funny, pry off the cover, take the nuts off, partially disassemble the thing and see if the center shaft nut isn't loose.

Photos of the completed project



The 2013 Geezerola Senior Radio.

With the RCA plug inserted and the wires connected to an antenna and a ground and with the earphone plugged in, the radio is turned on and ready to tune in stations.
Simply unplugging the earphone turns off the radio. No on/off switch is needed.



There is so much surplus room in the box after the wooden chassis is mounted,

a coil of antenna wire, the RCA plug and the high impedance earphone easily fits in the well.

The antenna and ground system

With this little regenerative radio, because it is ever so much more sensitive than any crystal radio, you do not need an antenna nearly so long and high as you need for a crystal radio. For local stations, a loud signal may be heard using antennas as short as 12 inches and distant stations at night many times come in well with antennas no longer than 10 feet.

One thing this radio shares in common with a crystal radio is the need for a good ground connection. Right now, I clip my radio's ground to the metal case of a radio that is plugged into the wall and it works great. Water pipes work really well too. The fact is, clipping the ground of this radio to just about any piece of metal seems to work as a ground, even another long piece of wire. Be absolutely certain that you NEVER connect the ground to a hot lead that is carrying AC voltage.

Tuning this radio for maximum sensitivity and selectivity

Of course, this radio, as do all regenerative radios, can go into self-oscillation if the throttle is turned up too high (set too far counterclockwise). Having the throttle set too high produces the infamous squeal that these radios are so notorious for and which, in the old days, caused them to be less than popular. The point of adjusting the throttle is to make it so the radio is just on the very knife-edge of going into oscillation. Just before oscillation, just before the audio sounds distorted, is when the radio reaches its peak amplification (best sensitivity) and when it tunes to its peak sharpness (best selectivity).

You can use the squeal of too much regeneration to your advantage once you learn the tricks. To find a weak station you want to listen to, turn the station tuning knob to a little lower than where you expect to find your station. Turn the throttle clockwise until you hear nothing and then counter clockwise until you first start to hear a faint "rushing" sound. If you tune upward, you will hear stations as whistles and squeals. Zero in on one of the squeals and try to make it as low in frequency as you can (this is called "zero beating") then adjust the throttle until the squeal or distortion just barely disappears. You will notice that if you change the tuning knob clockwise (tuning up in frequency) the squealing will start again and you can't go too far before you have to adjust the throttle clockwise to tone down the regeneration. By going back and forth between the tuning knob and the throttle, you can hunt across the dial for the station you want to listen to, but it is usually best to start low (counter clockwise) and work high (clockwise). Actually, it is a lot easier to learn how to operate a regenerative radio than this description would imply. Learning how to use the regeneration control is one of the fun aspects of this radio and soon you will become expert at it.

To get good sensitivity while maintaining reasonable selectivity, I find that a 15 picofarad capacitor works well to couple the antenna to the input tuned circuit. Even with this relatively light coupling, strong local stations might tend to interfere with stations that are near by on the same part of the dial. If this happens, I suggest you use a shorter antenna, maybe only 1 to 5 feet long, and that way the tuning will be very sharp. I think you will be surprised that even such a short antenna will still bring in stations quite nicely.

The best time of the day to have fun with these kinds of radios

During the daytime and during the summer months, about all that can be received with a little set like this is local broadcasting. Around my area, that means two stations of 24/7 nutty right wing trash the local broadcasters pander to and a couple of Mexican music and call-in stations. On the other hand, after sundown (on most evenings), electrified layers way up high in the outer fringes of our earth's atmosphere (the so-called "Ionosphere" also known as the "Thermosphere") allow radio waves from far away to be bent back down to the ground. Under ideal conditions, radio stations which are 200 to 300 (sometimes even more) miles away may be heard loudly and clearly. This long distance "refraction" or bending of the radio waves back to earth (a process called "skip") makes it possible to hear these distant stations, but it isn't like listening to the station next door. This "skipping" of radio waves off electrically charged layers in the upper atmosphere makes these signals subject to all kinds of strange things including interference from even more distant stations, fading in and out, some odd sounding distortions and sometimes there is even an echo effect. These so-called "propagation effects" can be annoying, but if you just wait a few seconds or minute or so, the signal generally returns.

Conclusions:

This little radio is an outgrowth of both the original 'Boy Electrician' single triode tube radio I built in 1958 and the 'Old Geezer Electrician' radio (my Armstrong "Crystal" Radio) that I built just recently. The (excellent) performance of this little radio is identical to the one tube radio I built way back in 1958 when I was a kid and to my Armstrong "Crystal" Radio, but I think the Geezerola Senior looks much nicer than either radio. Because the Geezerola Senior looks so nice and performs so well, this is the project I recommend you build if you are looking to build a simple radio with performance you can use.

As mentioned, it will vastly outperform, in every possible way, the best crystal radio and yet it is as easy and cheap to build as even the simplest and poorest performing crystal set. I know that not needing a battery and the utter simplicity of a crystal radio is greatly appealing to many people, but to get even poor performance out of a crystal set, you must sacrifice simplicity. If you wish to keep simplicity and yet have a little radio that performs extremely well, I sincerely recommend that you build my Geezerola or my Armstrong "Crystal" Radio instead.

By the way, if you build a radio based on what has been presented here, please drop me a line and describe it to me and, if you can, attach some pictures. I'd sure appreciate it if you would tell me how much you like the radio and how it performs for you. You can write me directly at my geojohn.org mail address.
Good luck.

The End

Having arrived this far, obviously you have a superior attention span and reading ability that far exceeds that of the majority of web users. I highly value the opinion of people such as yourself, so I ask you to briefly tell me:

Did you enjoy this article or were you disappointed?

Please visit my guest book and tell me before you leave my website.

If you have any detailed comments, questions, complaints or suggestions, I would be grateful if you would please **E-mail me directly**

If you would like to build a simpler version using ordinary tools and ordinary skills, you might like

My Armstrong "Crystal" Radio

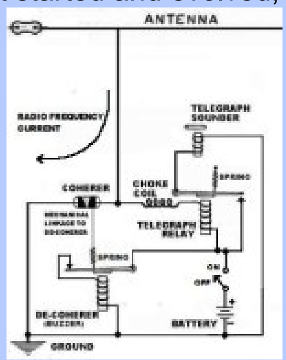
Or perhaps you would like to read the story of the little radio that launched my career in electronics

The Armstrong regenerative radio I built in 1958

You might like to read the story of my Armstrong regenerative radio that tunes shortwave and uses an FET for the detector,

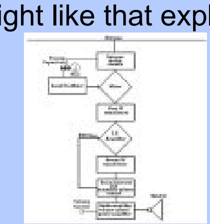
[My Regenerative Shortwave Radio.]

For more background on how early radio got started and evolved, perhaps you would like to read my essay on



The Coherer and other Detectors used in early radio

I have written a little essay you might like that explains some of the principles behind



How The Armstrong Superheterodyne Radio Works

or you can

Select another really entertaining radio article

or, as a last resort, you can
Return to my Home Page and look for something else

Chapter 7

Radio Frequency Energy Harvesting - Sources and Techniques

M. Pareja Aparicio, A. Bakkali, J. Pelegri-Sebastia, T. Sogorb, V. Llario and A. Bou

Additional information is available at the end of the chapter

http://dx.doi.org/10.5772/61722

Abstract

Energy harvesting technology is attracting huge attention and holds a promising future for generating electrical power. This process offers various environmentally friendly alternative energy sources. Especially, radio frequency (RF) energy has interesting key attributes that make it very attractive for low-power consumer electronics and wireless sensor networks (WSNs). Ambient RF energy could be provided by commercial RF broadcasting stations such as TV, GSM, Wi-Fi, or radar. In this study, particular attention is given to radio frequency energy harvesting (RFEH) as a green technology, which is very suitable for overcoming problems related to wireless sensor nodes located in harsh environments or inaccessible places. The aim of this paper is to review the progress achievements, the current approaches, and the future directions in the field of RF harvesting energy. Therefore, our aim is to provide RF energy harvesting techniques that open the possibility to power directly electronics or recharge secondary batteries. As a result, this overview is expected to lead to relevant techniques for developing an efficient RF energy harvesting system.

Keywords: Energy Harvesting, Energy Source, Radio Frequency, RFID, Wireless Sensor Networks

1. Introduction

As the demand for wireless sensor networks (WSNs) increases, the need for external power supply drastically increases as well. Besides the problems of recharging and replacing, size and weight, batteries are an exhaustible source with an adverse environmental effect. For these reasons, it is highly desirable to find an alternative solution in order to overcome these power limitations.

The environment represents a relatively good source of available energy compared with the energy stored in batteries or supercapacitors. In this context, energy harvesting, also known as power harvesting and energy scavenging, is an alternative process for primary batteries, where energy is obtained from the ambient environment. An energy harvester typically captures, accumulates, stores, and manages ambient energy in order to convert it into useful electrical energy for autonomous wireless sensor networks. The use of energy scavenging minimizes maintenance and cost operation; therefore, batteries can be eventually removed in WSNs as well as in portable electronic devices.

Many potential ways to harvest energy from environment are available, including solar and wind powers, radio frequency energy and ocean waves, and thermal energy and mechanical vibrations [1–3]. The publications on this topic in the literature are rising to a great extent. Hence, many papers have been published on energy harvesting as a feasible alternative to batteries. Work by Sardini et al. [4] proposed an autonomous sensor powered by mechanical energy coming from airflow velocity. Therefore, the battery-less sensor uses the power harvested in order to provide measurements of air's temperature and velocity. A completely different approach is proposed by Tan et al. in Ref. [5]. The authors have explored a system for wind-powered sensor node. By measuring the equivalent electrical voltage or the frequency of a wind turbine generator output, the wind speed measurement can be indirectly obtained. Based on the sensed wind speed information, the fire control management system provides the spreading condition of a wildfire, so that the fire fighting experts can perform an adequate fire suppression action.

This paper focuses on the energy harvesting technology using electromagnetic energy captured from multiple available ambient RF energy sources, such as TV and radio transmitters, mobile base stations, and microwave radios. This technique is very useful for sensors located in harsh environments or remote places, where other energy sources, such as wind or solar sources, are impracticable. In this context, this work presents an overview of advances achieved in RF harvesting field. The main components of an RF energy harvesting system are discussed in Section 2. Section 3 provides different measurements of the ambient radio frequency energy obtained in published papers. An introduction to RF harvesting energy in radio-frequency identification (RFID) technology is presented in Section 4. Finally, conclusions are drawn in Section 5.

2. Overview of radio frequency energy harvesting system

The basic structure of a radio frequency energy harvesting system consists of a receiving antenna, matching circuit, peak detector, and voltage elevator. Where electromagnetic waves are captured by the antenna, voltage is amplified using the matching circuit, signal is converted to a voltage value thanks to the peak detector, and finally this voltage output is adjusted using the voltage elevator.

The whole system formed by receiving antenna, matching network, and rectifier is usually known as a rectenna or an RF/direct current (DC), which is able to harvest high-frequency

energy in free space and convert it to DC power. The detail of each block is subsequently discussed in order to define specifications and limitations of the power conversion system.

Further, a block of power management and another for energy storage could be integrated into the energy harvesting system. The energy storage subsystem is responsible for storing all the captured energy and providing a constant output voltage.

Energy harvester is a promising power solution for WSNs. Instead of depending on centralized power sources for charging, sensor devices operate the existing energy in the environment. The DC voltage is stored in a holding capacitor or supercapacitor in order to power supply integrated circuits.

a. Antenna

RF energy harvesting technique needs, as mentioned in the previous section, an efficient antenna with a circuit capable of converting alternating current (AC) voltage to direct current voltage. The front end is a key component to ensure the successful operation of RFEH system. It has the duty of capturing electromagnetic waves, which will be used later to power the integrated system.

Moreover, the antenna efficiency is related to the frequency: energy obtained from an antenna with small bandwidth, than a wideband receiver antenna used to capture signals from multiple sources. RF antenna can harvest energy from a variety of sources, including broadcast TV signal (ultrahigh frequency (UHF)), mobile phones (900–950 MHz), or Local Area Network (2.45 GHz/ 5.8 GHz).

In principle, power harvested from RF signals is enough to supply microelectronic devices gradually; however, this power can dramatically rise by using an array configuration. Therefore, the maximum possible power can be achieved by properly arranging similar antennas (with the same matching circuit and power management) [6, 7], or by using antennas operating at different frequencies [8]. The trend is to include the antenna, usually patch antenna, and the rectifier on the same printed circuit board [9].

The equivalent electrical model of an antenna is an AC voltage source (V_{ant}) with series impedance (Z_{ant}), as illustrated in Figure 1. Amplitude of the AC voltage source depends on the available power (P_{AV}) and the real impedance (R_{ant}). The average power received (P_{AV}) depends on the power density (S) and the antenna effective area (A_e), as expressed in Eq. (1):

$$P_{AV} = S \cdot A \tag{1}$$

Apparent power received (S) can be calculated using the Friis transmission equation (Eq. (2)). S is a function of several parameters: the transmitted power (P_{TX}), the transmitting antenna gain (G_{TX}), the received antenna gain (G_{RX}), the wavelength (λ), loss factor (L_C), and the distance between transmitter and antenna (r):

$$S = P_{TX} \cdot G_{TX} \cdot G_{RX} \cdot L_C \cdot \left(\lambda / 4 \cdot \pi \cdot r\right) \tag{2}$$

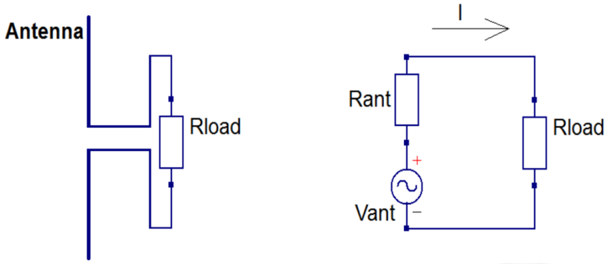


Figure 1. Antenna equivalent circuit.

The antenna impedance can be expressed by Eq. (3), where the real component is presented by two resistances: one is related to the material used (R_{loss}) and the other is due to the electromagnetic wave radiation (R_s). However, the imaginary component X_{ant} depends on the antenna structure, usually inductive for a loop antenna and capacitive for a patch antenna. Common Z_{ant} values are 300 Ω (closed dipole antenna), 75 Ω (open dipole antenna), and 50 Ω (wireless systems):

$$Z_{ant} = \left(R_{loss} + R_S\right) + jX_{ant} = R_{ant} + jX \tag{3}$$

Indeed, the concept of RF energy harvesting requires an efficient antenna with high performances. Hence, several researchers focused on highly efficient receivers for electromagnetic wave harvesting. Moon and Jung [10] proposed an interesting antenna design for RF energy harvesting system based on two radiators: the main one is a printed dipole radiator and the parasitic one with a loop structure. The parasitic radiator is suitable for receiving RF power in all directions from the main radiator. However, Xie et al. [11] designed a hexagonal microstrip patch antenna array that operates at 915 MHz, in order to achieve the maximum possible RF energy to convert into DC power for lighting light-emitting diodes (LED).

b. Matching circuit

Matching circuits are essentially used to match the antenna impedance to the rectifier circuit in order to achieve maximum power and improve efficiency, by using coils and capacitors [12, 13]. Several matching circuits are available; however, the main configurations that have been proposed are the transformer, the parallel coil, and the LC network, as shown in Figure 2.

For economic reasons, RFID tags and sensor networks use the shunt inductor and the LC network as matching networks instead of the transformer. Moreover, it is desirable for high-impedance antennas (e.g., dipole antenna) to use the parallel coil [12], whereas the LC network is used for small impedance antennas (e.g., Wi-Fi antenna) or when the available power P_{AV} is low [13].

As previously mentioned, the impedance matching circuit is designed to increase the voltage gain and reduce the transmission loss; this means that the impedance seen by the antenna is

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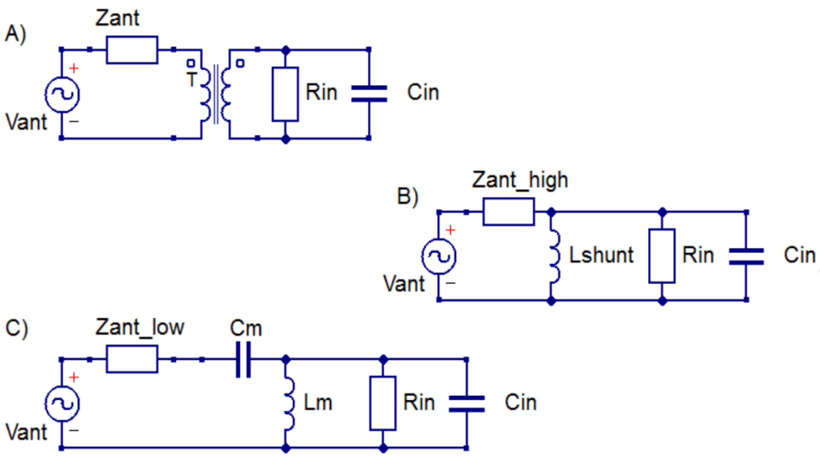

Figure 2. Matching network circuits: transformer (a), shunt inductor (b), and LC network (c) [12].

equal to the impedance of antenna [14]. The equivalent circuit and the normalized input voltage are shown in Figure 3. Therefore, Vin reaches its maximum level when α is equal to the unit, that is, when Rin and Rant are equal.

In radio frequency range, the impedance mismatch between the antenna and rectifier could be replaced by a tuning circuit, in order to adjust the receiver frequency [15, 16]. Multiband commercial antennas are typically equipped with filters [17]; however, the output power is lower than it should be [18]. An example of matching circuit impedance intended for television frequency band, formed by passive components and using the LC network, is discussed in Ref. [19].

Further, a shorted stub can be added to the matching circuit, which is represented by a wire with a length depending on wavelength and finishing on the ground plane. Therefore, the system performs as a tank circuit [9, 20]. However, in Ref. [21], the authors proposed an approximate method using a resistor in series with antenna. The current trend is to include antenna, impedance matching, and rectifier in a printed circuit board [19]. The RFEH system is designed on the same printed circuit board avoiding cable losses (cf. Figure 4).

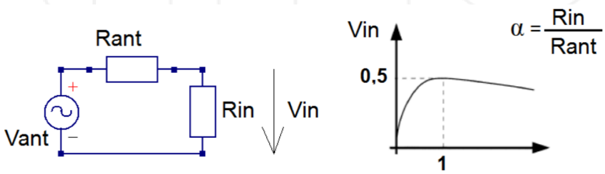

Figure 3. Transfer energy on matching circuit [14].

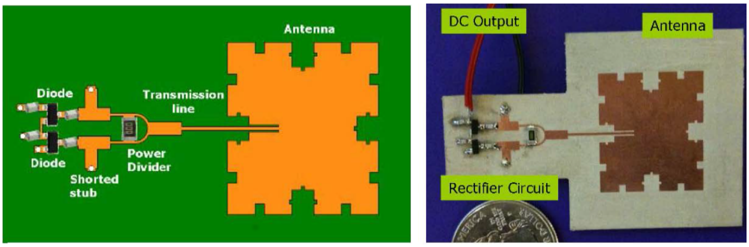

Figure 4. RFEH design circuit [9].

c. Rectifier

Radio frequency signal captured by the antenna is an alternating current (AC) signal. In order to get a DC signal out of AC signal and improve the efficiency of the RF–DC power conversion system, a rectifier circuit is used. Rectification subsystem or peak detector, which has been already used on crystal radio, consists only of diodes and capacitors.

When the distance from the RF source is far and the received power is not high enough, the rectifier input needs to be amplified in order to power the circuit (sensor networks or RFID tags require at least 3.3 V). The most popular rectifier used is a modified Dickson multiplier, which has the function of rectifying the radio frequency signal and increases the DC voltage. Moreover, many works have used complementary metal–oxide–semiconductor (CMOS) technology to replace the diodes [13, 22]. Other different ways to rectify AC signals have been introduced, including Greinacher circuit or voltage doubler [23], Cockcorft–Walton circuit [20], multiplier resonant [24, 25], Villance multiplier [26], and boost converter [23, 27].

Choice of rectification circuits depends on the radio frequency signal and power received, since different values of DC voltage could be obtained with the same circuit and different radio frequency sources. The multiplier is usually formed using different stages; each stage includes two diodes and two capacitors. The voltage output is more important with a large number of stages. However, because diode loss increases with the stage number, the system efficiency is affected. The impact of rectifier stage number on the power received is presented in Figure 5. For the low received power (Pin < 0 dBm), the output voltage (V_{out}) is practically independent of the stage number, while efficiency is good for fewer stages. The high voltage range is achieved when the power received is around 0 dBm and the number of stages is large, whereas efficiency decreases when V_{out} reached its maximum. Therefore, it seems difficult to achieve a good design due to the received signal influence on the RFEH system.

Multiplier efficiency (η_{rect}) depends on the input and output powers (P_{in_rect} and P_{out_rect}, respectively), as expressed in Eq. (4). However, the efficiency of RFEH system (η_{RFEH}) depends on the power generated (P_{out_dc}) and the power received (P_{in_rf}). The η_{RFEH} can be calculated using Eq. (5):

$$\eta_{rect} = P_{out\_rect} / P_{in\_rect} \quad (4)$$

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$$\eta_{\text{RFEH}} = P_{\text{out\_dc}} / P_{\text{in\_rf}} \tag{5}$$

Diodes commonly used as rectification components are Schottky diodes, while Germanium diodes are also used for radio circuit of the peak detector. Performance analysis of some Schottky diodes is outlined in Table 1.

Device	I_S (A)	R_S (Ω)	C_{JO} (pF)	V_J (V)	B_V (V)	I_{BV} (A)
SMS7630	5E-6	20	0.14	0.34	2	1E-04
HSMS-282X	2.2E-8	6	0.7	0.65	15	1E-04
HSCH-9161	12E-6	50	0.03	0.26	10	10E-12

Table 1. Parameters of Schottky diodes.

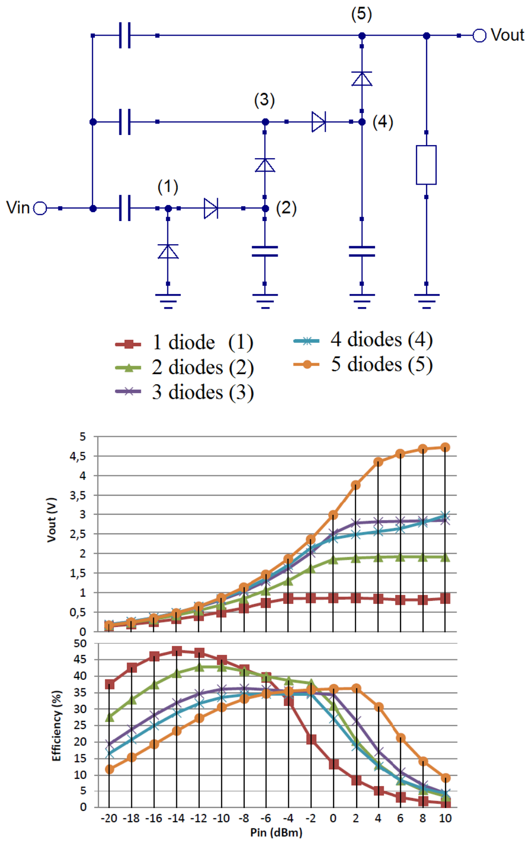

Figure 5. Stages multiplier versus output voltage and efficiency [28].

Rectifier equivalent circuit, as shown in Figure 6, is modeled by an input impedance $R_{in} \mid\mid C_{in}$, in addition to a current source depending on the input voltage, and a constant output resistor that presents the rectifier losses [14]. Output voltage value is determined by the stage number (N) of the multiplier.

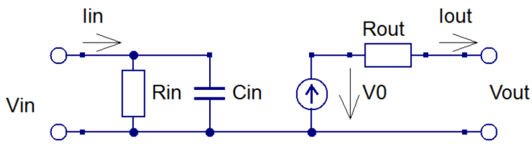

Figure 6. Multiplier equivalent circuit [14].

Further, multiplier equivalent circuit can also be obtained by using the mathematical equation [14], model simulation [12], or measurement [26].

3. Measurement of ambient radio frequency energy harvesting

As mentioned previously, an RFEH system is able to recover energy from available RF electromagnetic sources present in the ambient environment such as phone stations, radio, and television broadcasting. In Table 2, the main features of RFEH systems proposed in literature are summarized. As can be seen, the energy harvested is significantly very low that involves a decrease of the circuit performance.

Figure 7 shows the received power as a function of distance from RF power source at UHF. As it can be seen, for a free space distance of 40 m, the maximum theoretical power available for conversion is 1 μW and 7 μW for frequencies of 2.4 GHz and 900 MHz, respectively.

As mentioned above, many other sources of energy, including vibration, photovoltaic, and thermal, have been cleverly converted to useful energy using a variety of techniques. Table 2 presents some harvesting methods with their power generation capability.

Despite the fact that the power density of RFEH is lower than other sources, this powering method can be useful, especially for sensor nodes located in harsh environments, where other sources like wind or solar energies are not feasible.

Energy source	Power density (/cm^2)
RF	0.01 to 0.1 μW
Vibration	4 to 100 μW
Photovoltaic	10 μW to 10 mW
Thermal	20 μW to 10 mW

Table 2. Comparison of energy harvesting sources [29].

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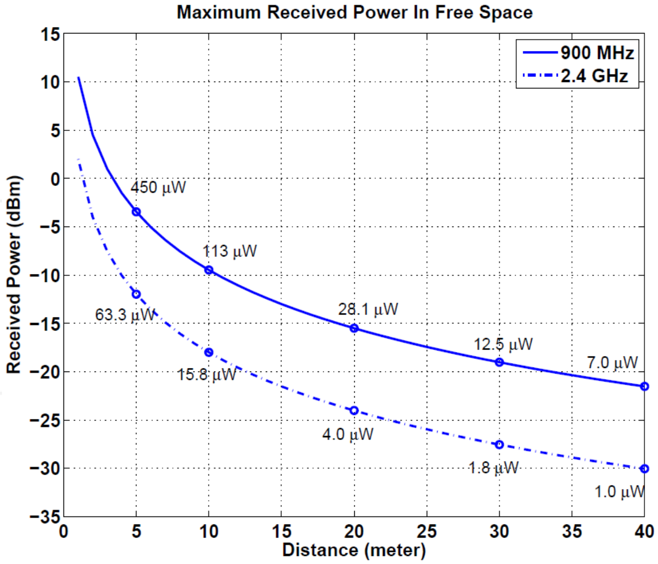

Figure 7. Received power versus distance [13].

Therefore, RFEH is a promising technology and an alternative source of energy to power the sensor nodes. As a result, these devices do not require any battery since they can use the power harvested from the ambient RF energy. Since battery replacement or its recharging is impracticable, autonomous WSNs need to exploit the RF ambient energy harvesting especially for long-duration applications.

It is important to note that the power density available depends on the radio frequency source and the distance. Values of this power are presented in Table 3 for different RF energy sources.

Source	Distance	Density power available
50kW AM radio station	5/10 [km]	159/40 [µW/m^2]
100W GSM base station	100/500/1000 [m]	800/32/8 [µW/m^2]
0,5 mobile phone	1/5/10 [m]	40/1.6/0.4 [mW/m^2]
1W Wi-Fi router	1/5/10 [m]	80/3.2/0.84 [mW/m^2]

Table 3. Power density on RFEH with different sources [30].

Table 4 provides a summary of results obtained from various studies in the RFEH field, with a brief description of the significant components used: RF source, antenna, matching circuit, and rectifier circuit.

Reference	Description	Frequency	Maximum Voltage	Maximum Performance	Power/Energy
BHA2006 [6]	Patch antenna array is used (4×4). Maximum power received is −10 dBm	2.4 GHz	n/a	n/a	373.248 μW
MIK2011a [8]	Using the same antenna for different frequency band, TV signal (74% to 42.6%) and RFID reader	470–770 MHz 950–956 MHz	n/a	74% (Pin=0 dBm) 54% (Pin=-20 dBm) 2% (Pin= −40 dBm)	0.74 mW (Pin=0 dBm) 5.4 μW (Pin=-20 dBm) 2 nW (Pin=−40 dBm)
UR2010 [15]	FM radio signals with loop antenna, tuned circuit, and Dickson charge pump 6 stages. AA supercapacitor is used to store energy	945 kHz	520 mV	n/a	60.4 μJ
BOU2010 [18]	Matching circuit using limited filter and rectifier with 1 stage. Maximum power received is −42 dBm (63 nW)	2.4 GHz	n/a	0.60%	400 pW
MIK2011b [31]	Patch antenna, matching circuit, and rectifier with 1 stage and boost converter	500–700 MHz	134 mV (Pin=−15 dBm)	18.2% (Pin=−20 dBm)	n/a
MIK2011c [32]	Microwave tooth antenna with filter, to matching circuit. A supercapacitor is used to store energy	470–505 MHz 520–560 MHz	3.7 V	> 50% (Pin=−5 dBm)	30 mW
AMA2011 [33]	Commercial UHF antenna and Dickson multiplier with 4 stages	UHF band	6 V	n/a	n/a

Table 4. Review of measurement of RFEH.

A comparison of the commercial requirements for sensor network nodes is presented in Table 5. Therefore, the use of RFEH for WSNs depends especially on the application, the distance from the base station, the radio-frequency band, distance between nodes, etc.

The results deduced from Tables 4 and 5 indicate that the RFEH is insufficient as a primary power source. Thus, it can be combined with other energy harvesting sources. As an example, for outdoor applications, when the base station is away from the sensor nodes, RFEH can be combined with photovoltaic energy. In a similar way, for human body sensors, this energy can be combined with thermal or vibration energy.

However, when the WSN is near to the base station, it is possible to use only RFEH as the power supply; in this case, the antenna and matching circuit must be compatible with the base station frequency. This system cannot be used for generic applications.

Operation Conditions	Crossbow MICAz	Waspmote	Intel IMote2	Tmote Sky (Telosb)
Radio standard	IEEE 802.15.4/Zig Bee	IEEE 802.15.4/Zig Bee	IEEE 802.15.4	IEEE 802.15.4
Typical range	100 m outdoor 30 m indoor	500 m	30 m	125 m outdoor 50 m indoor
Data rate (Kbps)	250	250	250	250
Sleep mode	15 μA	62 μA	390 μA	2.6 μA
Processor consumption	8 mA	9 mA	31–53 mA	500 μA
RX	19.7 mA	49.56 mA	44 mA	18.8 mA
TX	17.4 mA	50.26 mA	44 mA	17.4 mA
Supply voltage (min)	2.7 V	3.3 V	3.2 V	2.1 V

Table 5. Comparison of power consumption of sensor network nodes [34, 35].

Further, the energy-harvested design for powering sensor networks depends on different modes: sleep, transmission, reception, and minimal supply voltage required to run, (cf. Table 5), that is, it depends on the application.

4. RFEH and RFID

The RF harvesting technique is certainly a viable option for wide-range applications, including the passive RFID tags, where the signal used for communication is also used for powering [36, 37]. Therefore, RFID tags typically use the radio signal from a dedicated interrogator for power and communication. The antenna used could be designed for power harvesting and communication.

Table 6 shows the results of various studies that have been focused on RFID system powered by RFEH.

Reference	Frequency Band	Standard	Power Transmission	Antenna Gain	Distance	Efficient	Voltage	Consumption
OLG2010[9]	2.45 GHz	4 W EIRP	n/a	n/a	3.1–2.1 m	70%	1.6 V	1.6 V LED
KIT2005[20]	900 MHz	4 W EIRP	100 mW	7.5 dBi	3–3.5 m	n/a	0.6 V	2 μA
KIT2004[30]	2.45 GHz	RCD STD-1	300 mW	20 dBi	10 m	40%	> 1 V	30 μW

Table 6. Review of RFID system using RFEH power.

It is well known that RFID systems generate and radiate electromagnetic waves; thus, they are justifiably classified as radio systems. However, they are not considered as RFEH systems, since they get their energy from readers. Hence, an RFID system uses the radio frequency signal in order to power and activate the tag, whereas in RFEH system, the energy source is usually not controlled by the reader. The identification process is presented in Figure 8. The energy is sent by using a radio frequency signal in order to receive the information from tags. Furthermore, the passive tags, as no battery, are smaller and lighter than the active and semi-passive tags.

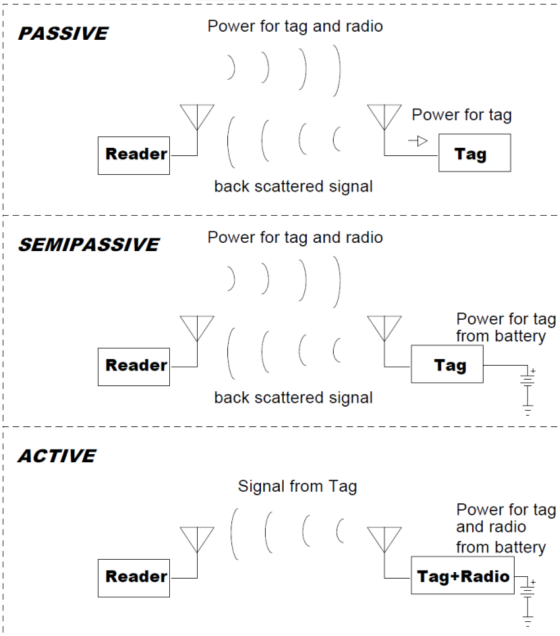

Figure 8. RFID systems [37].

Regarding RFID frequencies, there are four main frequency bands available for RFID systems:

- Low frequency (LF: 125–134 KHz).
- High frequency (HF: 13.56 MHz).
- Ultrahigh frequency (UHF: 956 MHz in USA and 866 MHz in Europe).
- Microwave band (2.45–5.8 GHz).

Despite the excellent progress made in the RFID technology, several issues still need to be addressed appropriately related to reliability, security, speed of communications, and evolution to a global standard. Therefore, it is highly suitable to develop compact transponders applicable for a long reading range, with a low price and a long life.

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5. Conclusion

RF energy harvesters open up new exciting possibilities in wireless communication and networking by enabling energy self-sufficient, environmentally friendly operation with practically infinite lifetimes, and synergistic distribution of information and energy in networks. The energy is harvested from commercial RF broadcasting stations, especially for powering wireless sensor networks or other applications that require only a small amount of energy (10^{-3} to 10^{-6} W). Further, RFID sensors can be powered by scavenging ambient power from radio frequency signals in order to prolong the lifetime to several decades and reduce maintenance costs.

This study is expected to provide a survey that offers a holistic view of RF energy harvesting process. Therefore, this paper covers various approaches of RF energy harvesting in order to meet the future demand for self-powered devices. All the subsystems of an RF harvester are discussed, including the receiving antenna, the matching circuit, and the rectifier. Hence, several research groups have proposed RF harvesters in order to achieve optimum power density and ensure a permanent power supply. Finally, RF energy harvesting is an emerging and active research area where more advancement is required to harvest energy efficiently.

Future works can be made to design antennas operating at several frequencies including at 2.3 GHz (Wimax), 2.4 GHz (WLAN), 2.6 GHz (LTE/4G), as well as 5.2 GHz (WLAN). Furthermore, the DC voltage of the rectenna needs to be improved in order to ensure that the optimum power transfer can be delivered.

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Author details

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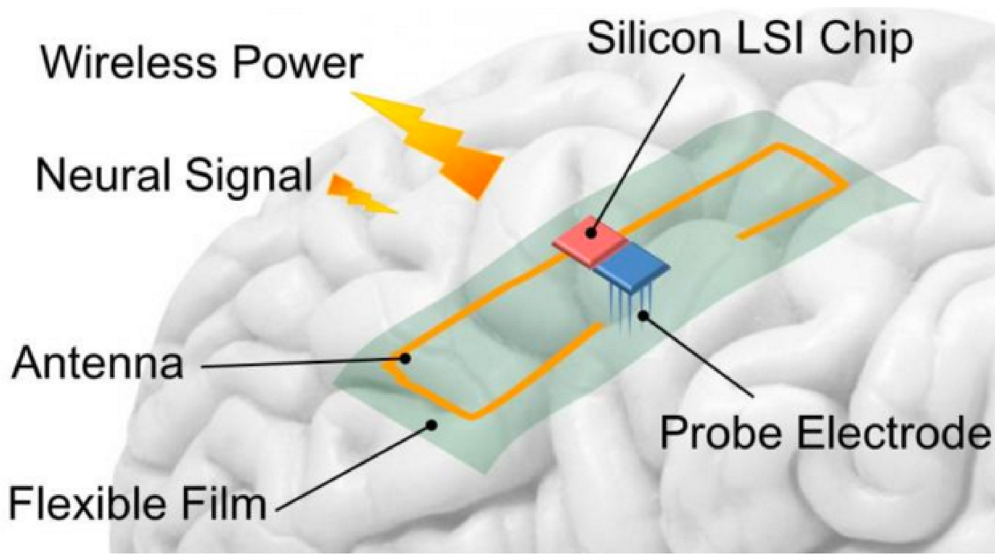
Powering brain implants without wires with thin-film wireless power transmission system

Avoids risk of infections through skull opening and leakage of cerebrospinal fluid, and allows for free-moving subjects and more flexible uses of brain-computer interfaces

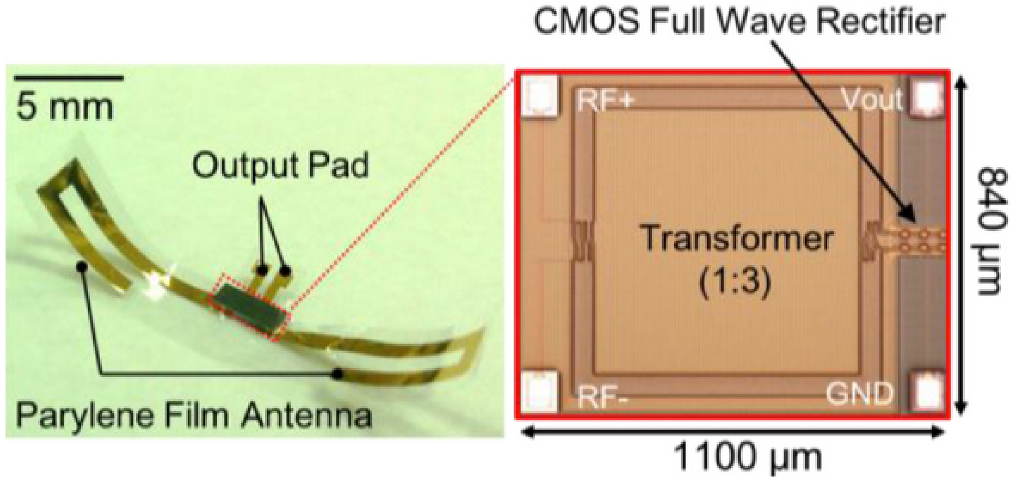
February 8, 2016



Schematic of proposed architecture of an implantable wireless-powered neural interface system that can provide power to implanted devices. Adding a transmitter chip could allow for neural signals to be transmitted via the antenna for external processing. (credit: Toyohashi University Of Technology)

A research team at Toyohashi University of Technology in Japan has fabricated an implanted wireless power transmission (WPT) device to deliver power to an implanted neural interface system, such as a brain-computer interface (BCI) device.

Described in an open-access paper in *Sensors* journal, the system avoids having to connect an implanted device to an external power source via wires through a hole in the skull, which can cause infections through the opening and risk of infection and leakage of the cerebrospinal fluid during long-term measurement. The system also allows for free-moving subjects, allowing for more natural behavior in experiments.

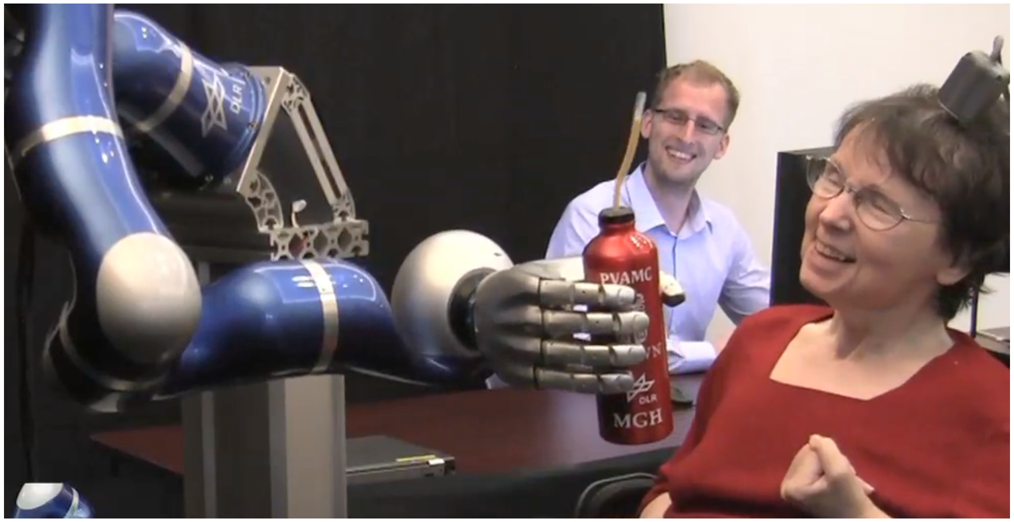


Photographs of fabricated flexible antenna and bonded CMOS rectifier chip with RF transformer (credit: Kenji Okabe et al./Sensors)

The researchers used a wafer-level packaging technique to integrate a silicon large-scale integration (LSI) chip in a thin (5 micrometers), flexible parylene film, using flip-chip (face-down) bonding to the film. The system includes a thin-film antenna and a rectifier to convert a radio-frequency signal to DC voltage (similar to how an RFID chip works). The entire system measures 27 mm × 5 mm, and the flexible film can conform to the surface of the brain.

Coventry University prof. Kevin Warwick turns on a light with a double-click of his finger, which triggers an implant in his arm (wired to a computer connected to the light). Adding an RF transmitter chip (and associated processing) to the Toyohashi system could similarly allow for controlling devices, but without wires. (credit: Kevin Warwick/element14)

The researchers plan to integrate additional functions, including amplifiers, analog-to-digital converters, signal processors, and a radio frequency circuit for transmitting (and receiving) data.



Tethered Braingate brain-computer interface for paralyzed patients (credit: Brown University)

Such a system could perform some of the functions of the Braingate system, which allows paralyzed patients to communicate (see "People with paralysis control robotic arms using brain-computer interface").

This work is partially supported by Grants-in-Aid for Scientific Research, Young Scientists, and the Japan Society for the Promotion of Science.

element14 | Kevin Warwick's BrainGate Implant

Abstract of *Co-Design Method and Wafer-Level Packaging Technique of Thin-Film Flexible Antenna and Silicon CMOS Rectifier Chips for Wireless-Powered Neural Interface Systems*

In this paper, a co-design method and a wafer-level packaging technique of a flexible antenna and a CMOS rectifier chip for use in a small-sized implantable system on the brain surface are proposed. The proposed co-design method optimizes the system architecture, and can help avoid the use of external matching components, resulting in the realization of a small-size system. In addition, the technique employed to assemble a silicon large-scale integration (LSI) chip on the very thin parylene film (5 μm) enables the integration of the rectifier circuits and the flexible antenna (rectenna). In the demonstration of wireless power transmission (WPT), the fabricated flexible rectenna achieved a maximum efficiency of 0.497% with a distance of 3 cm between antennas. In addition, WPT with radio waves allows a misalignment of 185% against antenna size, implying that the misalignment has a less effect on the WPT characteristics compared with electromagnetic induction.

References:

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